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In this Supplement to AP-42, new, revised and updated emissions data are presented for mobile sources; aircraft; transportation and marketing of petroleum liquids; waste solvent reclamation; tank and drum cleaning; hydrofluoric acid; phosphoric acid; sulfur recovery; wine making; harvesting of grain; primary lead smelting; coal cleaning; glass fiber manufacturing; phosphate rock processing; coal conversion; taconite ore processing; plywood veneer and layout operations; woodworking waste collection operations; and explosives detonation. There is also an expansion and revision of the Appendix A, miscellaneous data and conversion factors.

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COMPILATION

OF

AIR POLLUTION EMISSION FACTORS

INTRODUCTION

In the assessment and control of air pollution, there is a critical need for reliable and consistent data on the quantity and characteristics of emissions from the numerous sources that contribute to the problem. The large number of individual sources and the diversity of source types make conducting field measurements of emissions impractical source by source, at each point of release. The only feasible method of determining pollutant emissions for a given community or area is to make general emission estimates typical of each of the source types.

One of the most useful tools for estimating typical emissions is the "emission factor". This is an estimate of the rate at which a pollutant is released to the atmosphere as a result of some activity (such as combustion or industrial production) divided by the level of that activity (also expressed in terms of a temporal rate). In most cases, these factors are simply given as statistical or estimated averages, with no empirical information on the various process parameters (temperature, reactant concentrations, etc.) being considered in their calculation. However, for a few cases, such as in the estimation of volatile organic emissions from petroleum storage tanks, empirical formulas have been developed which relate emissions to such variables as tank diameter, liquid storage temperature, and wind velocity. Because of their superior precision, emission factors obtained from empirical formulas are more desirable and can usually be given higher accuracy ratings. Factors derived from statistical averages, however, if based on an adequate number of field measurements ("source tests"), also can be both precise and accurate within practical and useful limits.

Average or "typical" emission factors are obtained from a wide range of data of varying degrees of accuracy. The reader must be cautioned not to use these emission factors indiscriminately. That is, the general factors may not yield precise emission estimates for an individual installation. Only an onsite source test can provide data sufficiently accurate and precise to determine actual emissions for that source. Emission factors are most appropriate when used in air quality management applications and in diffusion models, for estimating the impact of proposed new sources upon ambient air quality and for community or nationwide air pollutant emission estimates.

Although emission factors may find use in the estimation of emissions expected from new or proposed sources, the user should review the literature and latest technology to determine if such sources are likely to exhibit emission characteristics different from those for a typical existing source. This document does not address RACT (Reasonably Available Control Technology), BACT (Best Available Control Technology), LAER (Lowest Achievable Emission Rate), NSPS (New Source Performance Standards), etc. Controlled emission factors and the general control device information presented herein are very limited and applicable to typical existing situations which are constantly changing. When determining the effect of various control device applications, the user should also consider the age, level of maintenance, and other considerations of effectiveness.

An example illustrates how the factors are used:

Suppose a sulfuric acid plant, with a production rate of 200 tons/day of 100 percent acid, operates at an overall SO_2 to SO_3 conversion efficiency of 97 percent. Using the formula given in Table 5.17-1 of this publication, the uncontrolled sulfur dioxide emissions can be calculated:

$$
\begin{aligned}
SO_2 \text{ emissions} &= [-13.65\ (\%\ \text{conversion efficiency}) + 1365] \times \text{production rate} \\
&= [-13.65\ (97\%) + 1365]\ \text{lb/ton acid} \times 200\ \text{tons acid/day} \\
&= 40\ \text{lb/ton acid} \times 200\ \text{tons acid/day} \\
&= 8000\ \text{lb/day}\ (3632\ \text{kg/day})
\end{aligned}
$$

The emission factors presented in AP-42 have been estimated using a wide spectrum of available techniques. The preparation/revision of each Section in this book involves, first of all, locating and obtaining information on that source category from available literature (including emission test reports). After the available data are reviewed, organized and analyzed, the process descriptions, process flowsheets and other background portions of the Section are prepared. Then, using the compiled information, representative emission factors are developed for each criteria pollutant emitted by each point source of the process category for which information is available. As stated above, these factors are usually obtained by simply averaging the respective numerical data obtained. When feasible, expected ranges or statistical confidence intervals are presented for further clarity. Occasionally, enough data exist to permit the development of empirical formulas or graphs relating emission factors to various process parameters such as stream temperature, sulfur content, catalysts, etc. In these cases, representative values of these process parameters are selected and substituted into the formulas or graphs to obtain representative emission factors, which are then tabulated. The pertinent formulas and graphical data are also included in the Section, to allow estimation of emission factors when process conditions differ from those selected as representative.

After a Section is drafted, it is circulated for technical review to personnel routinely familiar with the emission aspects of the particular activity. After these review comments are obtained and evaluated, the

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final Section is written, edited and published. To reflect an ever expanding data base, Sections may be revised at any time, and any review comments or data appropriate to this process are encouraged and requested.

The limited applicability of emission factors must be understood. To give some notion of the accuracy of the factors for a specific process, each set of factors has been ranked according to the amount of data upon which it is based. In the past, Sections have been rated only as a whole. Future updates, to the degree possible, will include ratings by pollutant for each process. Each rating has been based on the weighting of various information categories used to obtain the factor(s). These categories and associated numerical values are:

Measured emission data: 20 points maximum.
Process data: 10 points maximum.
Engineering analysis: 10 points maximum.

The emission data category rates the amount of measured source test data available for the development of the factor(s). The process data category involves such considerations as variability of the process and resultant effect on emissions, as well as the amount of data available on these variables. Finally, the engineering analysis category is concerned with data upon which a material balance or related calculation can be made. Depending on which information categories are employed to develop it, each set of factors is assigned a numerical score of from 5 to 40 points. Each numerical score is, in turn, converted to letter ratings which are presented throughout this publication as follows:

Numerical Rating	Letter Rating
5 or less	E (Poor)
6 to 15	D (Below average)
16 to 25	C (Average)
26 to 35	B (Above average)
36 to 40	A (Excellent)

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1.11 WASTE OIL COMBUSTION

by Jake Summers, EPA
and Pacific Environmental Services

1.11.1 General

The largest source of waste oil is used automotive crankcase oil, originating mostly from automobile service stations, and usually being found with small amounts of other automotive fluids. Other sources of waste oil include metal working lubricants, heavy hydrocarbon fuels, animal and vegetable oils and fats, and industrial oil materials.

In 1975, 57 percent of waste crankcase oil was consumed as alternative fuel in conventional boiler equipment (Section 1.3). The remainder was refined (15 percent), blended into road oil or asphalt (15 percent), or used for other nonfuel purposes (13 percent).[1]

1.11.2 Emissions and Controls

Lead emissions from burning waste oil depend on the lead content of the oil and on operating conditions. Lead content may vary from 800 to 11,200 ppm.[2] Average concentrations have been suggested as 6,000[1] and as 10,000 ppm[3]. During normal operation, about 50 percent of the lead is emitted as particulate with flue gas.[2,4] Combustion of fuel containing 10 percent waste oil gives particulate ranging from 14 to 19 percent lead. Ash content from combustion of fuels containing waste oil is higher than that for distillate or residual fuel oil, ranging from 0.03 to 3.78 weight percent, and lead accounts for about 35 percent of the ash produced in such combustion.[2]

Currently, controls are not usually applied to oil fired combustion sources. An exception is utility boilers, especially in the northeastern United States. Pretreatment by vacuum distillation, solvent extraction, settling and/or centrifuging minimizes lead emissions but may make waste oil use uneconomical.[2] High efficiency particulate control by means of properly operated and maintained fabric filters is 99 percent effective for 0.5-1 μm diameter lead and other submicron-sized particulate, but such a degree of control is infrequently used.[2]

Table 1.11-1. WASTE OIL COMBUSTION EMISSION FACTORS
EMISSION FACTOR RATING: B

Pollutant	Emission factor		References
	(kg/m^3)	(lb/10^3 gal)	
Particulate[a]	9.0 (A)	75 (A)	5
Lead[b]	9.0 (P)	75 (P)	1,2,3

[a] The letter A is for weight % of ash in the waste oil. To calculate the particulate emission factor, multiply the ash in the oil by 9.0 to get kilograms of particulate emitted per m^3 waste oil burned. Example: ash of waste oil is 0.5% the emission factor is 0.5 x 9.0 = 4.5 kg particulate per m^3 waste oil burned.

[b] The letter P indicates that the percent lead in the waste oil being processed should be multiplied by the value given in the table in order to obtain the emission factor. Average P= 1.0% (10,000 ppm). Refer to Reference 5.

References for Section 1.11

1. S. Wyatt, *et al.*, *Preferred Standards Path Analysis on Lead Emissions from Stationary Sources*, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, September 1974.

2. S. Chansky, *et al.*, *Waste Automotive Lubricating Oil Reuse as a Fuel*, EPA-600/5-74-032, U.S. Environmental Protection Agency, Washington, DC, September 1974.

3. *Final Report of the API Task Force on Oil Disposal*, American Petroleum Institute, New York, NY, May 1970.

4. *Background Information in Support of the Development of Performance Standards for the Lead Additive Industry*, EPA Contract No. 68-02-2085, PEDCo-Environmental Specialists, Inc., Cincinnati, OH, January 1976

5. *Control Techniques for Lead Air Emissions*, EPA-450/2-77-012, U.S. Environmental Protection Agency, Research Triangle Park, NC, December 1977.

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2.1 REFUSE INCINERATION

Revised by Robert Rosensteel

2.1.1 Process Description[1-4]

The most common types of incinerators consist of a refractory-lined chamber with a grate upon which refuse is burned. In some newer incinerators water-walled furnaces are used. Combustion products are formed by heating and burning of refuse on the grate. In most cases, since insufficient underfire (undergrate) air is provided to enable complete combustion, additional over-fire air is admitted above the burning waste to promote complete gas-phase combustion. In multiple-chamber incinerators, gases from the primary chamber flow to a small secondary mixing chamber where more air is admitted, and more complete oxidation occurs. As much as 300 percent excess air may be supplied in order to promote oxidation of combustibles. Auxiliary burners are sometimes installed in the mixing chamber to increase the combustion temperature. Many small-size incinerators are single-chamber units in which gases are vented from the primary combustion chamber directly into the exhaust stack. Single-chamber incinerators of this type do not meet modern air pollution codes.

2.1.2 Definitions of Incinerator Categories[1]

No exact definitions of incinerator size categories exist, but for this report the following general categories and descriptions have been selected:

1. *Municipal incinerators* – Multiple-chamber units often have capacities greater than 50 tons (45.3 MT) per day and are usually equipped with automatic charging mechanisms, temperature controls, and movable grate systems. Municipal incinerators are also usually equipped with some type of particulate control device, such as a spray chamber or electrostatic precipitator.

2. *Industrial/commercial incinerators* – The capacities of these units cover a wide range, generally between 50 and 4,000 pounds (22.7 and 1,800 kilograms) per hour. Of either single- or multiple-chamber design, these units are often manually charged and intermittently operated. Some industrial incinerators are similar to municipal incinerators in size and design. Better designed emission control systems include gas-fired afterburners or scrubbing, or both.

3. *Trench incinerators* – A trench incinerator is designed for the combustion of wastes having relatively high heat content and low ash content. The design of the unit is simple: a U-shaped combustion chamber is formed by the sides and bottom of the pit and air is supplied from nozzles along the top of the pit. The nozzles are directed at an angle below the horizontal to provide a curtain of air across the top of the pit and to provide air for combustion in the pit. The trench incinerator is not as efficient for burning wastes as the municipal multiple-chamber unit, except where careful precautions are taken to use it for disposal of low-ash, high-heat-content refuse, and where special attention is paid to proper operation. Low construction and operating costs have resulted in the use of this incinerator to dispose of materials other than those for which it was originally designed. Emission factors for trench incinerators used to burn three such materials[7] are included in Table 2.1-1.

4. *Domestic incinerators* – This category includes incinerators marketed for residential use. Fairly simple in design, they may have single or multiple chambers and usually are equipped with an auxiliary burner to aid combustion.

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Table 2.1-1. EMISSION FACTORS FOR REFUSE INCINERATORS WITHOUT CONTROLS[a]
EMISSION FACTOR RATING: A

Incinerator type	Particulates		Sulfur oxides[b]		Carbon monoxide		Hydrocarbons[c]		Nitrogen oxides[d]	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Municipal[e]										
Multiple chamber, uncontrolled	30	15	2.5	1.25	35	17.5	1.5	0.75	3	1.5
With settling chamber and water spray system[f]	14	7	2.5	1.25	35	17.5	1.5	0.75	3	1.5
Industrial/commercial										
Multiple chamber[g]	7	3.5	2.5[h]	1.25	10	5	3	1.5	3	1.5
Single chamber[i]	15	7.5	2.5[h]	1.25	20	10	15	7.5	2	1
Trench[j]										
Wood	13	6.5	0.1[k]	0.05	NA[l]	NA	NA	NA	4	2
Rubber tires	138	69	NA	NA	NA	NA	NA	NA	NA	NA
Municipal refuse	37	18.5	2.5[h]	1.25	NA	NA	NA	NA	NA	NA
Controlled air[m]	1.4	0.7	1.5	0.75	Neg	Neg	Neg	Neg	10	5
Flue-fed single chamber[n]	30	15	0.5	0.25	20	10	15	7.5	3	1.5
Flue-fed (modified)[o,p]	6	3	0.5	0.25	10	5	3	1.5	10	5
Domestic single chamber										
Without primary burner[q]	35	17.5	0.5	0.25	300	150	100	50	1	0.5
With primary burner[r]	7	3.5	0.5	0.25	Neg	Neg	2	1	2	1
Pathological[s]	8	4	Neg	Neg	Neg	Neg	Neg	Neg	3	1.5

[a] Average factors given based on EPA procedures for incinerator stack testing.

[b] Expressed as sulfur dioxide.

[c] Expressed as methane.

[d] Expressed as nitrogen dioxide.

[e] References 5 and 8 through 14.

[f] Most municipal incinerators are equipped with at least this much control: see Table 2.1-2 for appropriate efficiencies for other controls.

[g] References 3, 5, 10, 13, and 15.

[h] Based on municipal incinerator data.

[i] References 3, 5, 10, and 15.

[j] Reference 7.

[k] Based on data for wood combustion in conical burners.

[l] Not available.

[m] Reference 9.

[n] References 3, 10, 11, 13, 15, and 16.

[o] With afterburners and draft controls.

[p] References 3, 11, and 15.

[q] References 5 and 10.

[r] Reference 5.

[s] References 3 and 9.

5. *Flue-fed incinerators* – These units, commonly found in large apartment houses, are characterized by the charging method of dropping refuse down the incinerator flue and into the combustion chamber. Modified flue-fed incinerators utilize afterburners and draft controls to improve combustion efficiency and reduce emissions.

6. *Pathological incinerators* – These are incinerators used to dispose of animal remains and other organic material of high moisture content. Generally, these units are in a size range of 50 to 100 pounds (22.7 to 45.4 kilograms) per hour. Wastes are burned on a hearth in the combustion chamber. The units are equipped with combustion controls and afterburners to ensure good combustion and minimal emissions.

7. *Controlled air incinerators* – These units operate on a controlled combustion principle in which the waste is burned in the absence of sufficient oxygen for complete combustion in the main chamber. This process generates a highly combustible gas mixture that is then burned with excess air in a secondary chamber, resulting in efficient combustion. These units are usually equipped with automatic charging mechanisms and are characterized by the high effluent temperatures reached at the exit of the incinerators.

2.1.3 Emissions and Controls[1]

Operating conditions, refuse composition, and basic incinerator design have a pronounced effect on emissions. The manner in which air is supplied to the combustion chamber or chambers has, among all the parameters, the greatest effect on the quantity of particulate emissions. Air may be introduced from beneath the chamber, from the side, or from the top of the combustion area. As underfire air is increased, an increase in fly-ash emissions occurs. Erratic refuse charging causes a disruption of the combustion bed and a subsequent release of large quantities of particulates. Large quantities of uncombusted particulate matter and carbon monoxide are also emitted for an extended period after charging of batch-fed units because of interruptions in the combustion process. In continuously fed units, furnace particulate emissions are strongly dependent upon grate type. The use of rotary kiln and reciprocating grates results in higher particulate emissions than the use of rocking or traveling grates.[14] Emissions of oxides of sulfur are dependent on the sulfur content of the refuse. Carbon monoxide and unburned hydrocarbon emissions may be significant and are caused by poor combustion resulting from improper incinerator design or operating conditions. Nitrogen oxide emissions increase with an increase in the temperature of the combustion zone, an increase in the residence time in the combustion zone before quenching, and an increase in the excess air rates to the point where dilution cooling overcomes the effect of increased oxygen concentration.[14]

Table 2.1-2 lists the relative collection efficiencies of particulate control equipment used for municipal incinerators. This control equipment has little effect on gaseous emissions. Table 2.1-1 summarizes the uncontrolled emission factors for the various types of incinerators previously discussed.

Table 2.1-2. COLLECTION EFFICIENCIES FOR VARIOUS TYPES OF MUNICIPAL INCINERATION PARTICULATE CONTROL SYSTEMS[a]

Type of system	Efficiency, %
Settling chamber	0 to 30
Settling chamber and water spray	30 to 60
Wetted baffles	60
Mechanical collector	30 to 80
Scrubber	80 to 95
Electrostatic precipitator	90 to 96
Fabric filter	97 to 99

[a] References 3, 5, 6, and 17 through 21.

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3.0 INTERNAL COMBUSTION ENGINE SOURCES

NOTICE

Emission factors for hydrocarbons, carbon monoxides and oxides of nitrogen presented in Sections 3.1.1, 3.1.2, 3.1.4, 3.1.5 and 3.1.7, and in Appendix D, have been superseded by factors in *Mobile Source Emission Factors*, EPA-400/9-78-005, Office of Mobile Source Air Pollution Control, U.S. Environmental Protection Agency, 2565 Plymouth Road, Ann Arbor, MI 48105, March 1978. Factors appearing in the cited Sections for sulfur oxides and particulates have not been superseded and are still applicable.

AP-42 will be revised at some future date to reflect the factors in the document cited above. In the interim, copies of *Mobile Source Emission Factors* and related computer programs may be obtained from the Office of Mobile Source Air Pollution Control at the above address.

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3.2 OFF-HIGHWAY MOBILE SOURCES

The off-highway category of internal combustion engines embraces a wide range of mobile and semimobile sources. Emission data are reported in this section on the following sources: aircraft, locomotives, waterborne vessels (inboard and outboard), small general utility engines such as on lawnmowers and minibikes, agricultural equipment, heavy duty construction equipment, and snowmobiles.

3.2.1 AIRCRAFT

3.2.1.1 General

Aircraft engines are of two major categories, reciprocating piston and gas turbine.

In the piston engine, the basic element is the combustion chamber, or cylinder, in which mixtures of fuel and air are burned and from which energy is extracted by a piston and crank mechanism driving a propeller. The majority of aircraft piston engines have two or more cylinders and are generally classified according to their cylinder arrangement - either "opposed" or "radial". Opposed engines are installed in most light or utility aircraft, and radial engines are used mainly in large transport aircraft. Almost no singlerow inline or V-engines are used in current aircraft.

The gas turbine engine usually consists of a compressor, a combustion chamber and a turbine. Air entering the forward end of the engine is compressed and then heated by burning fuel in the combustion chamber. The major portion of the energy in the heated air stream is used for aircraft propulsion. Part of the energy is expended in driving the turbine, which in turn drives the compressor. Turbofan and turboprop (or turboshaft) engines use energy from the turbine for propulsion, and turbojet engines use only the expanding exhaust stream for propulsion. The terms "propjet" and "fanjet" are sometimes used for turboprop and turbofan, respectively.

The aircraft in the following tables include only those believed to be significant at present or over the next few years.

Few piston engine aircraft data appear here. Military fixed wing piston aircraft, even trainers, are being phased out. One piston engine helicopter, the TH-55A "Osage", sees extensive use at one training base at Ft. Rucker, AL (EPA Region IV), but engine emissions data are not available. Most civil piston engine aircraft are in general aviation service.

The fact that a particular aircraft brand is not listed in the following tables does not mean the emission factors cannot be calculated. It is the engine emissions and the time-in-mode (TIM) category which

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determine emissions. If these are known, emission factors can be calculated in the same way that the following tables are developed.

The civil and military aircraft classification system used is shown in Tables 3.2.1-1 and 3.2.1-2. Aircraft have been classified by kind of aircraft and the most commonly used engine for that kind. Jumbo jets normally have a miximum of about 40,000 pounds thrust per engine, and medium range jets about 14,000 pounds thrust per engine. Small piston engines develop less than 500 horsepower.

3.2.1.2 The Landing/Takeoff Cycle and Times-in-Mode

A landing/takeoff (LTO) cycle incorporates all of the normal flight and ground operation modes (at their respective times-in-mode), including: descent/approach from approximately 3000 feet (915 m) above ground level (AGL), touchdown, landing run, taxi in, idle and shutdown, startup and idle, checkout, taxi out, takeoff, and climbout to 3000 feet (915m) AGL.

In order to make the available data manageable, and to facilitate comparisons, all of these operations are conventionally grouped into five standard modes: approach, taxi/idle in, taxi/idle out, takeoff and climbout. There are exceptions. The supersonic transport (SST) has a descent mode preceding approach. Helicopters omit the takeoff mode. Training exercises involve "touch and go" practice. These omit the taxi/idle modes, and the maximum altitude reached is much lower. Hence, the duration (TIM) of the approach and climbout modes will be shorter.

Each class of aircraft has its own typical LTO cycle (set of TIMs). For major classes of aircraft, these are shown in Tables 3.2.1-3 and 3.2.1-4. The TIM data appearing in these tables should be used for guidance only and in the absence of specific observations. The military data are inappropriate to primary training. The civil data apply to large, congested fields at times of heavy activity.

All of the data assume a 3000 foot AGL inversion height and an average U.S. mixing depth. This may be inappropriate at specific localities and times, for which specific site and time inversion height data should be sought. Aircraft emissions of concern here are those released to the atmosphere below the inversion. If local conditions suggest higher or lower inversions, the duration (TIM) of the approach and climbout modes must be adjusted correspondingly.

A more detailed discussion of the assumptions and limitations implicit in these data appears in Reference 1.

Emission factors in Tables 3.2.1-9 and 3.2.1-10 were determined using the times-in-mode presented in Tables 3.2.1-3 and 3.2.1-4, and generally for the engine power settings given in Tables 3.2.1-5 and 3.2.1-6.

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Table 3.2.1-1. CIVIL AIRCRAFT CLASSIFICATION[a]

Aircraft	Engine[b]			
	No.	Mfg.	Type	Model/Series
Supersonic transport				
BAC/Aerospatiale Concorde	4	RR	TF	Olymp. 593-610
Short, medium, long range and jumbo jets				
BAC 111-400	2	RR	TF	Spey 511
Boeing 707-320B	4	P&W	TF	JT3D-7
Boeing 727-200	3	P&W	TF	JT8D-17
Boeing 737-200	2	P&W	TF	JT8D-17
Boeing 747-200B	4	P&W	TF	JT9D-7
Boeing 747-200B	4	P&W	TF	JT9D-70
Boeing 747-200B	4	RR	TF	RB211-524
Lockheed L1011-200	3	RR	TF	RB211-524
Lockheed L1011-100	3	RR	TF	RB211-22B
McDonnell-Douglas DC8-63	4	P&W	TF	JT3D-7
McDonnell-Douglas DC9-50	2	P&W	TF	JT8D-17
McDonnell-Douglas DC10-30	3	GE	TF	CF6-50C
Air carrier turboprops - commuter, feeder line and freighters				
Beech 99	2	PWC	TP	PT6A-28
GD/Convair 580	2	All	TP	501
DeHavilland Twin Otter	2	PWC	TP	PT6A-27
Fairchild F27 and FH227	2	RR	TP	R. Da. 7
Grumman Goose	2	PWC	TP	PT6A-27
Lockheed L188 Electra	4	All	TP	501
Lockhead L100 Hercules	4	All	TP	501
Swearingen Metro-2	2	GA	TP	TPE 331-3
Business jets				
Cessna Citation	2	P&W	TF	JT15D-1
Dassault Falcon 20	2	GE	TF	CF700-2D
Gates Learjet 24D	2	GE	TJ	CJ610-6
Gates Learjet 35, 36	2	GE	TF	TPE 731-2
Rockwell International Shoreliner 75A	2	GE	TF	CF 700
Business turboprops (EPA Class P2)				
Beech B99 Airliner	2	PWC	TP	PT6A-27
DeHavilland Twin Otter	2	PWC	TP	PT6A-27
Shorts Skyvan-3	2	GA	TP	TPE-331-2
Swearingen Merlin IIIA	2	GA	TP	TPE-331-3
General aviation piston (EPA Class P1)				
Cessna 150	1	Con	O	O-200
Piper Warrior	1	Lyc	O	O-320
Cessna Pressurized Skymaster	2	Con	O	TS10-360C
Piper Navajo Chieftain	2	Lyn	O	T10-540

[a] References 1 and 2.

[b] Abbreviations: TJ - tubojet, TF - turbofan, TP - turboprop, R - reciprocating piston, O - opposed piston. All - Detroit Diesel Allison Division of General Motors, Con - Teledyne/Continental, GA - Garrett AiResearch, GE - General Electric, Lyc - Avco/Lycoming, P&W - Pratt & Whitney, PWC - Pratt & Whitney Aircraft of Canada, RR - Rolls Royce.

Table 3.2.1-2. MILITARY AIRCRAFT CLASSIFICATION[a]

Aircraft mission (Class)	DOD Designation	Popular name	Manufacturer[b]	Service	Power plant		
					No. & Type[c]	Mfg.[b]	Designation
Combat	A-4	Skyhawk	McD-Doug	USN, USMC	1 TJ	P&W	J52, J65
	A-7	Corsair 2	Vought	USN	1 TF	All, P&W	TF41, TF30
	F-4	Phantom 2	McD-Doug	USAF, USN	2 TJ	GE	J79
	F-5	Freedom Fighter/ Tiger 2	Northrop	USAF	2 TJ	GE	J85
	F-14	Tomcat	Grumman	USN	2 TF	P&W	TF30, F401
	F-15A	Eagle	McD-Doug	USAF	2 TF	P&W	F100
	F-16	-	GD/FW	USAF	1 TF	P&W	F100
Bomber	B-52	Stratofortress	Boeing	USAF	8 TJ, TF	P&W	J57, TF33
Transport Patrol/Antisub	C-5A	Galaxy	GELAC	USAF	4 TF	GE	TF39
	C-130	Hercules	GELAC	USAF, USN, USCG	4 TP	All	T56
	KC-135	Stratotanker	Boeing	USAF	4 TJ	P&W	J57
	C-141	Starlifter	GELAC	USAF	4 TF	P&W	TF33
	P-3C	Orion	CALAC	USN	4 TP	All	T56
	S-3A	Viking	CALAC	USN	2 TF	GE	TF34
Trainer	T-34C	Turbo Mentor	Beech	USN	1 TP	PWC	PT6A
	T-38	Talon	Northrop	USAF	2 TJ	GE	J85
Helicopter	UH-1H	Iroquois/Huey	Bell	USA, USN	1 TS	Lyc, GE	T53, T58
	HH-3	Sea King/Jolly Green Giant	Sikorsky	USAF, USN, USCG	2 TS	GE	T58
	CH-47	Chinook	Boeing Vertol	USA	2 TS	Lyc	T55

[a] Reference 1. USN - U.S. Navy, USMC - U.S. Marine Corps, USAF - U.S. Air Force, USCG - U.S. Coast Guard, USA - U.S. Army.

[b] Abbreviations: All - Detroit Diesel Allison Division of General Motors, CALAC - Lockheed - California, GD/FW - General Dynamics, Ft. Worth, GE - General Electric, GELAC - Lockheed-Georgia, Lyc - Lycoming, McD-Doug - McDonnell Douglas, P&W - Pratt & Whitney, PWC - Pratt & Whitney Aircraft of Canada.

[c] TJ - Turbojet, TF - Turbofan, TP - Turboprop, TS - Turboshaft.

Table 3.2.1-3. TYPICAL DURATION FOR CIVIL LTO CYCLES AT LARGE CONGESTED METROPOLITAN AIRPORTS[a]

Aircraft	Mode					
	Taxi/ Idle out	Takeoff	Climbout	Approach	Taxi/ Idle in	Total
Commercial carrier						
Jumbo, long and medium range jet[b]	19.0	0.7	2.2	4.0	7.0	32.9
Turboprop[c]	19.0	0.5	2.5	4.5	7.0	33.5
Transport-piston	6.5	0.6	5.0	4.6	6.5	23.2
General aviation						
Business jet	6.5	0.4	0.5	1.6	6.5	15.5
Turboprop[c]	19.0	0.5	2.5	4.5	7.0	33.5
Piston[d]	12.0	0.3	5.0	6.0	4.0	27.3
Helicopter	3.5	-	6.5	6.5	3.5	20.0

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[a] Reference 3. Data given in minutes.
[b] Same times as EPA Classes T2, T3 and T4 (Note b, Table 3.2.1-5).
[c] Same times as EPA Classes T1 and P2 (Note b, Table 3.2.1-5).
[d] Same times as EPA Class P1 (Note b, Table 3.2.1-5).

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Table 3.2.1-4. TYPICAL DURATION FOR MILITARY LTO CYCLES[a]

Aircraft	TIM[b] Code	Mode					
		Taxi/ Idle out	Takeoff	Climbout	Approach	Taxi/ Idle in	Total
Combat[c]							
USAF	1	18.5	0.4	0.8	3.5	11.3	34.5
USN[d]	2	6.5	0.4	0.5	1.6	6.5	15.5
Trainer - Turbine							
USAF T-38	3	12.8	0.4	0.9	3.8	6.4	24.3
USAF general	4	6.8	0.5	1.4	4.0	4.4	17.1
USN[d]	2	6.5	0.4	0.5	1.6	6.5	15.5
Transport - Turbine[e]							
USAF general	5	9.2	0.4	1.2	5.1	6.7	22.6
USN[f]	6	19.0	0.5	2.5	4.5	7.0	33.5
USAF B-52 and KC-135	7	32.8	0.7	1.6	5.2	14.9	55.2
Military - Piston	8	6.5	0.6	5.0	4.6	6.5	23.2
Military - Helicopter	9	8.0	-	6.8	6.8	7.0	28.6

[a] Reference 1. Data given in minutes. USAF - U.S. Air Force, USN - U.S. Navy.

[b] TIM Code defined in Table 3.2.1-5.

[c] Fighters and attack craft only.

[d] Time-in-mode is highly variable. Taxi/idle out and in times as high as 25 and 17 minutes, respectively, have been noted. Use local data base if possible.

[e] Includes all turbine craft not specified elsewhere (i.e., transport, cargo, observation, patrol, antisubmarine, early warning, and utility).

[f] Same as EPA Class P2 for civil turboprops.

Table 3.2.1-5. ENGINE POWER SETTINGS FOR TYPICAL EPA LTO COMMERCIAL CYCLES[a]

Mode	Power setting (% thrust or horsepower)			
	Class T1, P2[b]	Class T2,T3, T4[b]	Class P1[b]	Helicopter
Taxi/Idle (out)	Idle	Idle	Idle	Undefined
Takeoff	100	100	100	
Climbout	90	85	75 - 100	
Approach	30	30	40	
Taxi/Idle (in)	Idle	Idle	Idle	

[a] References 1 and 3.

[b] As defined by EPA (Reference 3):

Class T1 is all aircraft turbofan or turbojet engines except Class T5 of rated power less than 8000 lbs thrust.

Class T2 is all turbofan or turbojet aircraft engines except Classes T3, T4 and T5 of rated power of 8000 lbs thrust or greater.

Class T3 is all aircraft gas turbine engines of the JT3D model family.

Class T4 is all aircraft gas turbine engines of the JT8D model family.

Class T5 is all aircraft gas turbine engines on aircraft designed to operate at supersonic speeds.

Class P1 is all aircraft piston engines, except radial.

Class P2 is all aircraft turboprop engines.

Table 3.2.1-6. ENGINE POWER SETTINGS FOR A TYPICAL LTO MILITARY CYCLE[a]

Mode	Power setting (% thrust or horsepower)			
	Military transport	Military jet	Military piston	Military helicopter
Taxi/Idle (out)	Idle	Idle	5 - 10	Idle
Takeoff	Military	Military or Afterburner	100	-
Climbout	90 - 100	Military	75	60 - 75
Approach	30	84 - 86	30	45 - 50
Taxi/Idle (in)	Idle	Idle	5 - 10	Idle

[a] Reference 1.

TABLE 3.2.1-7. MODAL EMISSION RATES–CIVIL AIRCRAFT ENGINES[a]

Model-Series Mfg.[b] Type[b]	Mode	Fuel Rate		CO		NO_x[c]		Total HC[d]		SO_x[e]		Particulates[f]	
		lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr
250B17B All. TP	Idle	63	28.58	6.13	2.78	0.09	0.041	1.27	0.576	0.06	0.03		
	Takeoff	265	120.2	2.07	0.939	1.75	0.794	0.07	0.032	0.27	0.12		
	Climbout	245	111.1	2.21	1.00	1.46	0.662	0.09	0.041	0.25	0.11		
	Approach	85	38.56	4.13	1.87	0.19	0.086	0.44	0.200	0.09	0.04		
501D22A All. TP	Idle	610	276.7	26.60	12.07	2.15	0.975	10.74	4.87	0.61	0.28		
	Takeoff	2376	1078	4.85	2.20	21.10	9.57	0.67	0.304	2.38	1.08		
	Climbout	2198	997	4.53	2.05	20.27	9.19	1.96	0.889	2.20	1.00		
	Approach	1140	517.1	5.81	2.64	8.54	3.87	2.23	1.01	1.14	0.52		
TPE 331-3 GA TP	Idle	112.0	50.8	6.89	3.12	0.320	0.145	8.86	4.02	0.11	0.05	0.3[g]	0.14[g]
	Takeoff	458.0	207.7	0.350	0.159	5.66	2.57	0.050	0.023	0.46	0.21	0.8	0.36
	Climbout	409.0	185.5	0.400	0.181	4.85	2.20	0.060	0.027	0.41	0.19	0.6	0.27
	Approach	250.0	113.4	1.74	0.789	2.48	1.12	0.160	0.073	0.25	0.11	0.6	0.27
TPE331-2 GA TP	Idle	105.0	47.6	6.73	3.05	0.27	0.22	9.58	4.34	0.11	0.05	(Assume 331-3 data)	
	Takeoff	405.0	183.7	0.38	0.172	4.14	1.88	0.16	0.072	0.41	0.18		
	Climbout	372.0	168.7	0.51	0.231	3.69	1.67	0.15	0.068	0.37	0.17		
	Approach	220.0	99.8	3.65	1.66	1.82	0.826	0.59	0.268	0.22	0.10		
TPE 731-2 GA TF	Idle	181.0	82.1	11.11	5.04	0.54	0.245	4.05	1.84	0.18	0.08		
	Takeoff	1552.0	704.0	1.86	0.844	29.8	13.52	0.14	0.064	1.55	0.70		
	Climbout	1385.0	628.2	1.80	0.816	23.68	10.74	0.12	0.054	1.39	0.63		
	Approach	521.0	236.3	9.53	4.32	3.59	1.63	1.51	0.685	0.52	0.24		
CJ 610-2C GE TJ	Idle	510.0	231.3	79.05	35.86	0.46	0.209	9.18	4.16	0.51	0.23		
	Takeoff	2780.0	1261.0	75.06	34.05	11.68	5.30	0.28	0.127	2.78	1.26		
	Climbout	2430.0	1102.0	65.61	29.76	8.99	4.08	0.49	0.222	2.43	1.10		
	Approach	1025.0	464.9	90.20	40.91	1.54	0.698	2.77	1.26	1.03	0.46		
CF700-2D GE TF	Idle	460	208.7	71.30	32.34	0.41	0.186	8.28	3.76	0.46	0.21		
	Takeoff	2607	1182	57.35	26.01	14.60	6.62	0.26	0.118	2.61	1.18		
	Climbout	2322	1053	58.05	26.33	9.98	4.53	0.23	0.104	2.32	1.05		
	Approach	919	416.9	56.98	25.85	1.65	0.748	1.29	0.585	0.92	0.42		
CF6-6D GE TF	Idle	1063	482.2	65.06	29.51	4.88	2.21	21.79	9.88	1.06	0.48	0.04[g]	0.02[g]
	Takeoff	13750	6237	8.25	3.74	467.5	212.1	8.25	3.74	13.75	6.24	0.54	0.24
	Climbout	11329	5139	6.80	3.03	309.2	140.2	6.80	3.08	11.33	5.14	0.54	0.24
	Approach	3864	1753	23.18	10.51	41.54	18.84	6.96	3.16	3.86	1.75	0.44	0.20
CF6-50C GE TF	Idle	1206	547	88.04	39.93	3.02	1.37	36.18	16.41	1.21	0.55	(Assume CF6-6D data)	
	Takeoff	18900	8573	0.38	0.172	670.95	304.3	0.19	0.086	18.90	8.57		
	Climbout	15622	7104	4.70	2.13	462.0	209.6	0.16	0.073	15.62	7.10		
	Approach	5280	2395	22.70	10.30	52.8	23.95	0.05	0.023	5.28	2.40		

TABLE 3.2.1-7 (CONTINUED)

Model-Series Mfg.[b] Type[b]	Mode	Fuel Rate lb/hr	Fuel Rate kg/hr	CO lb/hr	CO kg/hr	NO_x[c] lb/hr	NO_x[c] kg/hr	Total HC[d] lb/hr	Total HC[d] kg/hr	SO_x[e] lb/hr	SO_x[e] kg/hr	Particulates[f] lb/hr	Particulates[f] kg/hr
JT3D-7 P&W TF	Idle	1013	459.5	140.8	63.87	2.23	1.01	124.6	56.52	1.01	0.46	0.45[g]	0.20[g]
	Takeoff	9956	4516	8.96	4.06	126.4	57.34	4.98	2.26	9.96	4.52	8.25	3.7
	Climbout	8188	3714	15.56	7.06	78.6	35.65	3.28	1.49	8.19	3.71	8.5	3.9
	Approach	3084	1399	60.14	27.28	16.35	7.42	6.48	2.94	3.08	1.40	8.0	3.6
JT8D-17 P&W TF	Idle	1150	521.6	39.10	17.74	3.91	1.77	10.10	4.58	1.15	0.52	0.36[g,h]	0.16[g,h]
	Takeoff	9980	4527	6.99	3.17	202.6	91.90	.50	0.227	9.98	4.53	3.7	1.7
	Climbout	7910	3588	7.91	3.59	123.4	55.97	.40	0.181	7.91	3.59	2.6	1.2
	Approach	2810	1275	20.23	9.18	19.39	8.80	1.41	0.640	2.81	1.28	1.5	0.68
JT9D-7 P&W TF	Idle	1849	838.7	142.4	64.59	5.73	2.60	55.10	24.99	1.85	0.84	2.2[f]	1.0
	Takeoff	16142	7322	3.23	1.47	474.6	215.3	0.81	0.367	16.14	7.32	3.75	1.7
	Climbout	13193	5984	6.60	2.99	282.3	128.0	1.32	0.599	13.19	5.98	4.0	1.8
	Approach	4648	2108	44.62	20.24	36.25	16.44	4.65	2.11	4.65	2.11	2.3	1.0
JT9D-70 P&W TF	Idle	1800	816.5	61.20	27.76	5.76	2.61	12.24	0.55	1.80	0.82	(assume JT9D-7 data)	
	Takeoff	19380	8791	3.88	1.76	600.8	272.5	2.91	1.32	19.38	8.79		
	Climbout	15980	7248	4.79	2.17	386.7	175.4	2.40	1.09	15.98	7.25		
	Approach	5850	2654	7.61	3.45	47.39	21.50	2.63	1.19	5.85	2.65		
JT15D-1 PWC TF	Idle	215	97.52	19.46	8.83	0.54	0.245	7.48	3.39	0.22	0.10		
	Takeoff	1405	637.3	1.41	0.640	14.19	6.44	0	0	1.41	0.64		
	Climbout	1247	565.6	1.25	0.567	11.35	5.15	0	0	1.25	0.57		
	Approach	481	218.2	11.45	5.19	2.45	1.11	1.59	0.721	0.48	0.22		
PT6A-27 PWC TP	Idle	115	52.16	7.36	3.34	0.28	0.127	5.77	2.62	0.12	0.05		
	Takeoff	425	192.8	0.43	0.195	3.32	1.51	0	0	0.43	0.19		
	Climbout	400	181.4	0.48	0.218	2.80	1.27	0	0	0.40	0.18		
	Approach	215	97.52	4.95	2.24	1.80	0.816	0.47	0.213	0.22	0.10		
PT6A-41 PWC TP	Idle	147	66.63	16.95	7.69	0.29	0.132	14.94	6.78	0.15	0.07		
	Takeoff	510	231.3	2.60	1.18	4.07	1.85	0.89	0.404	0.51	0.23		
	Climbout	473	214.6	3.07	1.39	3.58	1.62	0.96	0.435	0.47	0.21		
	Approach	273	123.8	9.50	4.31	1.27	0.576	6.20	2.81	0.27	0.12		
Spey 555-15[i] RR TF	Idle	915	415	83.2	37.7	1.6	0.7	86.0	43.5	0.92	0.42		
	Takeoff	5734	2600	6.5	3.0	109.2	49.5	29.5	13.4	5.73	2.60		
	Climbout	4677	2121	0.0	0.0	68.7	31.2	2.5	1.1	4.68	2.12		
	Approach	1744	791	34.8	15.8	10.2	4.6	14.3	6.5	1.74	0.79		
Spey MK511[g,i] RR TF	Idle	946	429.1	104.4	47.36	0.785	0.356	80.03	36.30	0.95	0.43	0.17	0.077
	Takeoff	7057	3201	16.16	7.33	156.7	71.08	13.97	6.34	7.06	3.20	16.0	7.3
	Climbout	5752	2609	0.0	0.0	116.8	52.98	0.0	0.0	5.75	2.61	10.0	4.5
	Approach	2204	999.7	48.71	22.09	16.00	7.26	20.56	9.33	2.20	1.00	1.5	0.68
M45H-01[i] RR (Bristol) TF	Idle	366	166.0	55.63	25.23	0.622	0.282	11.53	5.23	0.37	0.17		
	Takeoff	3590	1628	7.18	3.26	32.31	14.66	0.718	0.326	3.59	1.62		
	Climbout	3160	1433	9.48	4.30	25.28	11.47	0.632	0.287	3.16	1.43		
	Approach	1067	484.0	53.56	24.29	3.57	1.62	6.61	3.00	1.07	0.48		

TABLE 3.2.1-7 (CONTINUED)

Model-Series Mfg.[b] Type[b]	Mode	Fuel Rate lb/hr	Fuel Rate kg/hr	CO lb/hr	CO kg/hr	NO_x^c lb/hr	NO_x^c kg/hr	Total HC[d] lb/hr	Total HC[d] kg/hr	SO_x^e lb/hr	SO_x^e kg/hr	Particulates[f] lb/hr	Particulates[f] kg/hr
RB-211-22B[i]	Idle	1718	779.3	137.6	64.42	5.31	2.41	100.1	45.36	1.72	0.78		
RR TF	Takeoff	14791	6709	5.62	2.55	504.1	228.7	29.14	13.22	14.79	6.71		
	Climbout	12205	5536	14.89	6.75	301.9	136.9	8.30	3.76	12.21	5.54		
	Approach	4376	1985	93.78	42.54	32.26	14.63	32.16	14.59	4.38	1.99		
RB-211-524[i]	Idle	1769	802.4	35.91	16.29	4.74	2.15	5.43	2.46	1.77	0.80		
RR TF	Takeoff	17849	8096	7.32	3.32	660.4	299.6	1.96	0.889	17.85	8.10		
	Climbout	14688	6662	7.34	3.33	470.0	213.2	2.50	1.13	14.69	6.67		
	Approach	5450	2472	11.72	5.32	62.89	28.53	0.545	0.247	5.45	2.47		
RB-401-06[i]	Idle	330	149.7	10.07	4.57	0.825	0.374	0.924	0.419	0.33	0.15		
RR TF	Takeoff	2400	1089	2.40	1.09	30.0	13.61	0.120	0.054	2.40	1.09		
	Climbout	2130	966.2	2.77	1.26	24.07	10.92	0.107	0.049	2.13	0.97		
	Approach	775	351.5	5.04	2.29	3.88	1.76	0.155	0.070	0.78	0.35		
Dart RDa7[i]	Idle	411	186.4	37.61	17.06	0.292	0.132	25.52	11.58	0.41	0.19		
RR TP	Takeoff	1409	639.1	4.79	2.17	8.51	3.86	8.75	3.97	1.41	0.64		
	Climbout	1248	566.1	4.26	1.93	5.55	2.52	2.15	0.975	1.25	0.57		
	Approach	645	292.6	21.48	9.74	0.568	0.258	0.0	0.0	0.65	0.29		
Tyne[g, i]	Idle	619	280.8	40.79	18.50	0.477	0.216	6.63	3.01	0.62	0.28		
RR TP	Takeoff	2372	1076	1.21	0.549	27.11	12.30	2.87	1.31	2.37	1.08		
	Climbout	2188	922.5	1.29	0.585	25.23	11.44	2.63	1.19	2.19	0.99		
	Approach	1095	496.7	11.30	5.13	9.00	4.08	2.68	1.22	1.10	0.50		
Olympus 593[i]	Idle	3060	1388	342.7	155.4	9.72	4.41	119.3	54.11	3.06	1.39		
MK610	Takeoff	52200	23673	1513.8	686.5	542.9	246.2	151.4	68.7	52.2	23.7		
RR (Bristol)	Climbout	19700	8936	275.8	125.1	169.4	76.84	31.52	14.30	19.70	8.94		
TJ	Descent	5400	2449	426.6	193.5	18.9	8.6	132.3	60.0	5.4	2.4		
	Approach	9821	4455	451.8	204.9	41.25	18.71	93.30	42.32	9.82	4.46		
0-200	Idle	8.24	3.75	5.31	2.42	0.013	0.006	0.239	0.107	0.0	0		
Con. O	Takeoff	45.17	20.53	44.0	20.0	0.220	0.100	0.940	0.427	0.01	0		
	Climbout	45.17	20.53	44.0	20.0	0.220	0.100	0.940	0.427	0.01	0		
	Approach	25.50	11.59	30.29	13.75	0.029	0.013	0.847	0.385	0.01	0		
TSIO-360C	Idle	11.5	5.21	6.81	3.09	0.022	0.009	1.59	0.723	0.0	0.0		
Con. O	Takeoff	133.	60.3	143.9	65.3	0.36	0.16	1.22	0.55	0.03	0.01		
	Climbout	99.5	45.1	95.6	43.4	0.43	0.20	0.95	0.43	0.02	0.01		
	Approach	61.0	27.7	60.7	27.5	0.23	0.10	0.69	0.31	0.01	0.01		
6-285-B	Idle	72.12	10.03	26.23	11.90	0.0334	0.0152	0.773	0.350	0.0	0.0		
(Tiara)	Takeoff	153.0	69.39	152.7	69.3	0.899	0.408	1.78	0.806	0.03	0.01		
Con. O	Climbout	166.0	52.61	110.9	50.3	0.913	0.414	1.39	0.632	0.02	0.01		
	Approach	83.5	37.88	85.39	38.77	0.394	0.179	1.343	0.609	0.02	0.01		

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TABLE 3.2.1-7 (CONCLUDED)

Model-Series[a] Mfg.[b] Type[b]	Mode	Fuel Rate		CO		NO_x[c]		Total HC[d]		SO_x[e]		Particulate[f]	
		lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr
O-320 Lyc. O	Idle	9.48	4.30	10.21	4.63	0.0049	0.0022	0.350	0.159	0.0	0.0		
	Takeoff	89.1	40.4	96.0	43.5	0.195	0.088	1.05	0.475	0.02	0.01		
	Climbout	66.7	30.3	66.0	29.9	0.265	0.120	0.826	0.375	0.01	0.01		
	Approach	46.5	21.1	56.8	25.8	0.044	0.020	0.895	0.406	0.01	0.0		
IO-320-DIAD Lyc. O	Idle	7.84	3.56	4.86	2.20	0.009	0.0041	0.283	0.128	0.0	0.0		
	Takeoff	91.67	41.57	109.3	49.55	0.167	0.0756	1.047	0.475	0.02	0.01		
	Climbout	61.42	27.85	54.55	24.74	0.344	0.156	0.588	0.267	0.01	0.01		
	Approach	37.67	17.08	35.57	16.13	0.128	0.058	0.460	0.208	0.01	0.0		
IO-360-B Lyc. O	Idle	8.09	3.68	7.26	3.29	0.0094	0.0042	0.398	0.180	0.0	0.0		
	Takeoff	103.0	46.7	123.5	56.0	0.205	0.093	1.03	0.469	0.02	0.01		
	Climbout	71.7	32.5	70.5	32.0	0.329	0.149	0.585	0.265	0.01	0.01		
	Approach	36.6	16.6	25.3	11.5	0.372	0.169	0.355	0.161	0.01	0.0		
TIO-540- J2B2 Lyc. O	Idle	25.06	11.36	32.42	14.70	0.0097	0.0044	1.706	0.774	0.01	0.0		
	Takeoff	259.7	117.8	374.5	169.8	0.094	0.043	3.21	1.46	0.05	0.02		
	Climbout	204.5	92.7	300.8	136.4	0.0481	0.0218	3.40	1.54	0.04	0.02		
	Approach	99.4	45.1	125.4	56.9	0.138	0.0623	1.33	0.604	0.02	0.01		

[a] References 1,2.

[b] Abbreviations: All – Detroit Diesel Allison Division of General Motors; Con – Teledyne/Continental; GA – Garrett AiResearch; GE – General Electric; Lyc – Avco/Lycoming; P&W – Pratt & Whitney; PWC – Pratt & Whitney Aircraft of Canada; RR – Rolls Royce; TJ – Turbojet; TF – Turbofan; TP – Turboprop; O – Reciprocating (Piston) Opposed.

[c] Nitrogen oxides reported as NO_2.

[d] Total hydrocarbons. Volatile organics, including unburned hydrocarbons and organic pyrolysis products.

[e] Sulfur oxides and sulfuric acid reported as SO_2. Calculated from fuel rate and 0.05 wt% sulfur in Jet A and Jet B fuel, or 0.01 wt% sulfur in aviation gasoline. For turbine engines, the conversion is therefore SO_x (lb/hr) = 10^{-3} (fuel rate), and for piston engines, the conversion is SO_x (lb/hr) = 2×10^{-4} (fuel rate).

[f] All particulate data are from Reference 4. Does not include condensible compounds.

[g] The indicated reference does not specify series number for this model engine.

[h] "Diluted smokeless" JT 8D. Note: JT8D is a turbofan engine and is not equivalent to the JT8 (Military J52) turbojet engine.

[i] All Rolls Royce data are based upon an arbitrary 7% idle, which does not reflect the actual situation. In reality, Rolls Royce engines will idle at 5-6% with correspondingly higher emissions (Reference 2).

[j] The Olympus 593 engine used in the Concorde SST has a unique 6-mode LTO cycle.

TABLE 3.2.1-8. MODAL EMISSION RATES – MILITARY AIRCRAFT ENGINES[a]

Model-Series (Civil Version) Mfg[h] Type[h]	Mode	Fuel Rate		CO		NO_x[b]		Total HC[c]		SO_x[d]		Particulates[e,f]	
		lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr
J57-P-22 (JT3C) P&W TJ	Idle	1087	493	64.4	29.2	2.7	1.2	55.8	25.3	1.1	0.5	8.3	3.8
	Takeoff	8358	3791	14.9	6.8	93.3	42.3	5.4	2.4	8.4	3.8	12.0	5.4
	Climbout	8358	3791	14.9	6.8	93.3	42.3	5.4	2.4	8.4	3.8	12.0	5.4
	Approach	1693	768	39.8	18.1	5.0	2.3	21.0	9.5	1.7	0.8		
J65-W-20 Wr. TJ	Idle	1333	605	66.9	30.3	3.7	1.7	5.0	2.3	1.3	0.6		
	Takeoff	6421	2913	49.6	22.5	48.5	22.0	0.2	0.1	6.4	2.9		
	Climbout	6421	2913	49.6	22.5	48.5	22.0	0.2	0.1	6.4	2.9		
	Approach	3260	1479	52.6	23.9	23.7	10.8	0.9	0.4	3.3	1.5		
J79-GE-10 GE TJ	Idle	1100	499	48.0	21.8	3.2	1.5	9.8	4.4	1.1	0.5	57.8	26.2
	Takeoff	35390	16053	611.9	277.6	241.3	109.5	17.2	7.8	35.4	16.1	299.7	135.9
	Climbout	9680	4482	52.0	23.6	151.8	68.9	16.0	7.3	9.9	4.5	77.7	35.2
	Approach	6190	2808	45.6	20.7	69.9	31.7	4.1	1.9	6.2	2.8	67.0 (nom)	30.4
J85-GE-5F GE TJ for T38	Idle	524	328	93.3	42.3	0.7	0.3	15.7	7.1	0.5	0.2		
	Takeoff	8470	3942	245.6	111.4	22.0	10.0	6.8	3.1	8.5	3.9		
	Climbout	1297	588	55.8	25.3	3.0	1.4	4.5	2.0	1.3	0.6		
	Approach	1098	498	63.7	28.9	3.0	1.4	1.3	0.6	1.1	0.5		
J85-GE-21 GE TJ for F-5	Idle	400	181	63.6	28.4	0.5	0.2	9.7	4.4	0.4	0.2		
	Takeoff	10650	4831	387.7	175.8	59.6	27.0	1.1	0.5	10.7	4.9		
	Climbout	3200	1452	69.0	31.3	16.0	7.3	0.8	0.4	3.2	1.5		
	Approach	1200	544	55.5	25.1	3.5	1.6	3.1	1.4	1.2	0.5		
TF30-P-6B (JFT 10) P&W TF for A-7	Idle	689	313	47.0	21.3	0.9	0.4	12.9	5.9	0.7	0.3		
	Takeoff	6835	3100	21.1	9.6	82.3	37.3	6.9	3.1	6.8	3.1		
	Climbout	6835	3100	21.1	9.6	82.3	37.3	6.9	3.1	6.8	3.1		
	Approach	3550	1610	22.4	10.2	23.7	10.8	10.5	4.8	3.6	1.6		
TF30-P-412A (JFT 10A) P&W TJ for F-14	Idle	999	453	68.1	30.9	2.4	1.1	38.4	17.4	1.0	0.5	26.5	12.0
	Takeoff	40000	18144	600.0	272.2	270.0	122.5	40.0	18.1	40.0	18.1	693.2	314.4
	Climbout	7394	3354	15.7	7.1	123.2	55.9	0.7	0.3	7.4	3.4	61.7	29.0
	Approach	2598	1178	39.5	17.9	18.4	8.3	2.9	1.3	2.6	1.2	46.8 (nom)	21.2
TF33-P-3/5/7 (JT3D) P&W TJ	Idle	846	384	74.9	34.0	1.5	0.7	77.8	35.3	0.8	0.4	4.4	2.0
	Takeoff	9979	4526	13.0	5.9	109.8	49.8	3.0	1.4	10.0	4.5	79.8	36.2
	Climbout	7323	3322	13.2	6.0	65.9	29.9	2.9	1.3	7.3	3.3	102.5	46.5
	Approach	3797	1722	34.2	15.5	27.7	12.6	14.4	6.5	3.8	1.7	53.1	24.1
TF34-GE-400 GE TJ	Idle	457	207	35.0	15.9	0.6	0.3	7.1	3.2	0.5	0.2		
	Takeoff	3796	1722	9.3	4.2	20.9	9.5	1.6	0.7	3.8	1.7		
	Climbout	3796	1722	9.3	4.2	20.9	9.5	1.6	0.7	3.8	1.7		
	Approach	1296	588	19.4	8.8	10.0	4.5	0.8	0.4	1.3	0.6		

TABLE 3.2.1-8 (CONCLUDED)

Model-Series (Civil-Version) Mfg[h] Type[h]	Mode	Fuel Rate		CO		NO[b]		Total HC[c]		SO_x[d]		Particulates[e,f]	
		lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr
TF39-GE-1	Idle	1130	513	75.7	34.3	3.4	1.5	26.0	11.8	1.1	0.5	0.3[g]	0.1
(JT4A)	Takeoff	11410	5176	8.0	3.6	319.5	144.9	2.3	1.0	11.4	5.2	17.1[g]	7.8
GE TJ	Climbout	5740	2604	4.0	1.8	160.7	72.9	1.1	0.5	5.7	2.6	8.0[g]	3.6
	Approach	5740	2604	4.0	1.8	160.7	72.9	1.1	0.5	5.7	2.6	8.0[g]	3.6
TF41-A-2	Idle	1070	485	114.6	52.0	1.4	0.6	70.8	32.1	1.1	0.5		
All. TF	Takeoff	9040	4101	14.4	6.5	201.4	91.4	5.3	2.4	9.0	4.1		
	Climbout	9040	4101	14.4	6.5	201.4	91.4	5.3	2.4	9.0	4.1		
	Approach	5314	2410	27.5	12.5	56.6	25.7	12.9	5.9	5.3	2.4		
F100-PW-100	Idle	1060	481	20.5	9.3	4.2	1.9	2.4	1.1	1.1	0.5	0.1[g]	0.05
(JTF 22)	Takeoff	44200	20049	2435.4	1104.7	729.3	330.8	4.4	2.0	44.2	20.0	0.0[g]	0.0
P&W TF	Climbout	10400	4717	18.7	8.5	457.6	207.6	0.5	0.2	10.4	4.7	8.6[g]	3.9
	Approach	3000	1361	9.0	4.1	33.0	15.0	1.8	0.8	3.0	1.4	1.0[g]	0.5
PT6A-27	Idle	115	52	7.36	3.34	0.28	0.13	5.77	2.62	0.12	0.05		
PWC TP	Takeoff	425	193	0.43	0.20	3.32	1.51	0	0	0.43	0.20		
	Climbout	400	181	0.48	0.22	2.80	1.27	0	0	0.40	0.18		
	Approach	215	98	5.0	2.24	1.80	0.82	0.47	0.21	0.22	0.10		
T56-A7	Idle	548	249	17.5	7.9	2.1	1.0	11.5	5.2	0.5	0.2	1.6	0.7
All. TP	Takeoff	2079	943	4.4	2.0	19.3	8.8	0.8	0.4	2.1	1.0	3.7	1.7
	Climbout	1908	865	4.6	2.1	17.6	8.0	0.9	0.4	0.9	0.4	3.0	1.4
	Approach	1053	478	3.7	1.7	7.8	3.5	0.5	0.2	1.1	0.5	3.0	1.4
T53-L-11D	Idle	142	64	4.2	1.9	0.2	0.1	9.0	4.1	0.14	0.06		
(LTC1)	Climbout[i]	679	308	2.0	0.9	5.0	2.3	0.2	0.1	0.68	0.31		
Lyc TS	Approach	679	308	2.0	0.9	5.0	2.3	0.2	0.1	0.68	0.31		
T55-L-11A	Idle			29.5	13.4	0.8	4.0	4.0	1.8				
(LTC4)	Climbout[i]			14.5	6.6	18.6	8.4	0.2	0.1				
Lyc TS	Approach			12.9	5.9	9.1	4.1	0.3	0.1				
T58-GE-5	Idle	133	60	22.5	10.2	0.2	0.1	12.9	5.9	0.1	0.05	0.1	0.05
GE TS	Climbout[i]	886	402	5.0	2.3	6.4	2.9	0.7	0.3	0.9	0.4	0.8	0.4
	Approach	886	402	5.0	2.3	6.4	2.9	0.7	0.3	0.9	0.4	0.8	0.4

[a] Reference 1.

[b] Nitrogen oxides reported as NO_2.

[c] Total hydrocarbons. Volatile organics, including unburned hydrocarbons and organic pyrolysis products.

[d] Sulfur oxides and sulfuric acid reported as SO_2. Calculated from fuel rate and 0.05 wt% sulfur in JP-4 or JP-5 fuel, or 0.01 wt% sulfur in aviation gasoline. For turbine engines, the conversion is therefore SO_x (lb/hr) = 10^{-3} (fuel rate), and for piston engines, the conversion is SO_x (lb/hr) = 2 x 10^{-4} (fuel rate).

[e] Includes all "condensible particulates," and thus may be much higher than solid particulates alone (except as noted in g below).

[f] "Nom." data are interpolated values assumed for calculational purposes, in the absence of experimental data.

[g] Dry particles only.

[h] For abbreviations, see footnote, Table 3.1.1-2.

[i] "Takeoff" mode is undefined for helicopters.

TABLE 3.2.1-9. EMISSION FACTORS PER AIRCRAFT PER LANDING/TAKEOFF CYCLE–CIVIL AIRCRAFT[a]

Commercial Carrier Aircraft	Power Plant[b]			CO		NO_x[c]		Total HC[d]		SO_x[e]		Particulates	
	No.	Mfg.	Model-Series	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg
Short, Medium, Long Range and Jumbo Jets													
BAC/Aerospatiale Concorde	4	RR	Olymp 593	847.0	384.0	91.0	41.0	246.0	112.0	14.1	6.4		
BAC 111-400	2	RR	Spey 511	103.36	46.88	15.04	6.82	72.42	32.85	1.70	0.77	1.46	0.66
Boeing 707-320B	4	P&W	JT3D-7	262.64	119.12	25.68	11.64	218.24	99.00	4.28	1.94	4.52	2.05
Boeing 727-200	3	P&W	JT8D-17	55.95	25.38	29.64	13.44	13.44	6.09	3.27	1.48	1.17	0.53
Boeing 737-200	2	P&W	JT8D-17	37.30	16.92	19.76	8.96	8.96	4.06	2.18	0.99	0.78	0.35
Boeing 747-200B	4	P&W	JT9D-7	259.64	117.76	83.24	37.76	96.92	43.96	7.16	3.25	5.20	2.36
Boeing 747-200B	4	P&W	JT9D-70	108.92	49.40	107.48	48.76	22.40	10.16	7.96	3.61	5.20	2.36
Boeing 747-200B	4	RR	RB211-524	66.76	30.28	124.9	56.65	10.00	4.54	7.52	3.41		
Lockheed L1011-200	3	RR	RB211-524	50.07	27.71	93.66	42.48	7.50	3.40	5.64	2.56		
Lockheed L1011-100	3	RR	RB211-22B	199.4	90.44	64.29	29.16	138.4	62.77	4.95	2.24		
McDonnell-Douglas DC8-63	4	P&W	JT3D-7	262.64	119.12	25.68	11.64	218.24	99.00	3.27	1.48	1.17	0.53
McDonnell-Douglas DC9-50	2	P&W	JT8D-17	37.30	16.92	19.76	8.96	8.96	4.06	2.18	0.99	0.78	0.35
McDonnell-Douglas DC10-30	3	GE	CF6-50C	116.88	53.01	49.59	22.17	47.10	21.36	4.98	2.26	0.21	0.10
Air Carrier Turboprops – Commuter, Feeder Line and Freighters													
Beech 99	2	PWC	PT6A-28	7.16	3.25	0.82	0.37	5.08	2.30	0.18	0.08		
GD/Convair 580	2	All	501	24.38	11.06	21.66	9.82	9.82	4.45	0.92	0.42		
DeHavilland Twin Otter	2	PWC	PT6A-27	7.16	3.25	0.82	0.37	5.08	2.30	0.18	0.08		
Fairchild F27 and FH227	2	RR	R.Da.7	36.26	16.45	0.92	0.42	22.42	10.17	0.58	0.26		
Grumman Goose	2	PWC	PT6A-27	7.16	3.25	0.82	0.37	5.08	2.30	0.18	0.08		
Lockheed L188 Electra	4	All	501	48.76	22.12	43.32	19.65	19.64	8.91	1.84	0.83		
Lockheed L100 Hercules	4	All	501	48.76	22.12	43.32	19.65	19.64	8.91	1.84	0.83		
Swearingen Metro-2	2	GA	TPE 331-3	6.26	2.84	1.16	0.53	7.68	3.48	0.16	0.07	0.46	0.21

TABLE 3.2.1-9 (CONCLUDED)

General Aviation Aircraft	Power Plant[b]			CO		NO_x[c]		Total HC[d]		SO_x[e]		Particulates	
	No.	Mfg.	Model-Series	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg
Business Jets													
Cessna Citation	2	P&W	JT15D-1	19.50	8.85	2.00	0.91	6.72	3.05	0.40	0.18		
Dassault Falcon 20	2	GE	CF700-2D	76.14	34.54	1.68	0.76	7.40	3.36	0.78	0.35		
Gates Learjet 24D	2	GE	CJ610-6	88.76	40.26	1.58	0.72	8.42	3.82	0.84	0.38		
Gates Learjet 35, 36	2	GE	TPE 731-2	11.26	5.11	3.74	1.58	3.74	1.70	0.92	0.42		
Rockwell International Shoreliner 75A	2	GE	CF 700	76.14	34.54	1.08	0.76	7.40	3.36	0.78	0.35		
Business Turboprops (EPA Class P2)													
Beech B99 Airliner	2	PWC	PT6A-27	7.16	3.25	0.82	0.37	5.08	2.30	0.18	0.08		
DeHavilland Twin Otter	2	PWC	PT6A-27	7.16	3.25	0.82	0.37	5.08	2.30	0.18	0.08		
Shorts Skyvan-3	2	GA	TPE-331-2	6.44	2.92	0.883	0.400	8.40	3.81	0.16	0.07	0.46	0.21
Swearingen Merlin IIIA	2	GA	TPE-331-3	6.28	2.85	1.15	0.522	7.71	3.50	0.16	0.07	0.46	0.21
General Aviation Piston (EPA Class P1)													
Cessna 150	1	Con	0-200	8.32	3.77	0.02	0.01	0.23	0.10	0.0	0.0		
Piper Warrior	1	Lyc	0-320	14.37	6.52	0.02	0.01	0.26	0.12	0.0	0.0		
Cessna Pressurized Skymaster	2	Con	TS10-360C	33.10	15.01	0.13	0.06	1.15	0.52	0.0	0.0		
Piper Navajo Chieftain	2	Lyc	T10-540	96.24	43.65	0.02	0.01	1.76	0.80	0.0	0.0		

[a] Reference 2.

[b] Abbreviations: All – Detroit Diesel Allison Division of General Motors; Con – Teledyne/Continental; GA – Garrett AiResearch; GE – General Electric; Lyc – Avco/Lycoming; P&W – Pratt & Whitney; PWC – Pratt & Whitney Aircraft of Canada; RR – Rolls Royce.

[c] Nitrogen oxides reported as NO_2.

[d] Total hydrocarbons. Volatile organics, including unburned hydrocarbons and organic pyrolysis products.

[e] Sulfur oxides and sulfuric acid reported as SO_2.

Table 3.2.1-10. EMISSIONS FOR MILITARY AIRCRAFT LANDING/TAKEOFF CYCLES[a]

Aircraft		Power plant No.	Power plant Model/Series	TIM[b] code	CO lb	CO kg	NO_x[c] lb	NO_x[c] kg	Total HC[d] lb	Total HC[d] kg	SO_x[e] lb	SO_x[e] kg	Particulates lb	Particulates kg
Fixed Wing - Turbine														
A-4C	Skyhawk	1	J65-W-20	2	16.62	7.54	2.15	0.98	1.10	0.50	0.46	0.21		
A-7	Corsair 2	1	TP30-P-68	2	11.10	5.03	2.05	0.93	3.18	1.44	0.35	0.16		
A-7	Corsair 2	1	TF41-A-2	2	25.79	11.70	4.83	2.19	15.76	7.15	0.52	0.24		
B-52H	Stratofortress	8	TF-33-P-3/5/8	7	504.08	228.65	53.04	24.06	505.76	229.41	10.24	4.64	94.08	42.67
F-4	Phantom 2	2	J79-GE-10	2	32.24	14.62	10.88	4.94	4.94	2.24	1.46	0.66	33.92	15.39
F-5	Freedom Fighter/Tiger	2	J85-GE-21	1	76.64	34.76	2.10	0.95	10.04	4.55	0.76	0.34		
F-14	Tomcat	2	TF30-P-412A	2	39.88	18.09	7.62	3.46	17.36	7.87	1.24	0.56	24.24	11.00
F-15A	Eagle	2	F100-PW-100	1	54.40	24.68	29.96	13.58	2.68	1.22	2.32	1.06	0.44	0.20
F-16	-	1	F100-PW-100	1	27.20	12.34	14.98	6.79	1.34	0.61	1.16	0.53	0.22	0.10
C-5A	Galaxy	4	TF39-GE-1	5	82.12	37.25	79.60	36.11	28.08	12.74	3.84	1.74	4.12	1.87
C-130	Hercules	4	T56-A-7	6	32.36	14.68	9.60	4.35	20.28	9.20	1.60	0.73	4.36	1.98
KC-135	Stratotanker	4	J57-P-22	7	220.92	100.21	24.64	11.18	185.56	84.17	5.36	2.43	31.36	14.22
C-141	Starlifter	4	TF33-P-3/5/7	5	92.40	41.91	19.20	8.71	87.68	39.77	3.00	1.36	33.00	14.97
T-34C	Turbo Mentor	1	PT6A-27	2	1.73	0.73	0.15	0.07	1.27	0.58	0.03	0.01		
T-38	Talon	2	J85-GE-5F	3	82.72	32.99	1.22	0.55	10.42	4.73	0.62	0.28		
P-3C	Orion	4	T56-A-7	6	32.36	14.68	9.60	4.35	20.28	9.20	1.60	0.73	4.36	1.98
S3A	Viking	2	TF34-GE-400	6	34.18	15.50	4.04	1.83	6.44	2.92	1.02	0.46		
Helicopters - Turbine														
UH-1H	Iroquois/Huey	1	T53-L-11D	9	1.55	0.70	1.19	0.54	2.53	1.15	0.20	0.09		
HH-3	Sea King/Jolly Green Giant	2	T58-GE-5	9	13.54	6.14	3.02	1.37	6.78	3.08	0.44	0.20	0.40	0.18
CH-47	Chinook	2	T55-L-11A	9	20.94	9.50	6.68	3.03	2.10	0.95				

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[a] Reference 1.

[b] Defined in Table 3.2.1-5.

[c] Nitrogen oxides reported as NO_2.

[d] Total hydrocarbons. Volatile organics, including unburned hydrocarbons and organic pyrolysis products.

[e] Sulfur oxides and sulfuric acid reported as SO_2.

3.2.1.3 Modal Emission Rates and Emission Factors per LTO Cycle

The first step in the calculation of aircraft emission factors is the development of a set of modal emission rates. These represent the quantity of pollutant released per unit time in each of the standard modes. Each mode is characterized by an engine power setting (given in Tables 3.2.1-5 and 3.2.1-6) and a fuel rate (the quantity of fuel consumed per unit time).

The following procedure is for calculation of aircraft emission factors per LTO cycle, starting with engine modal emission rates:

1) For a specific aircraft, determine the number and model of engines, using for example, Tables 3.2.1-1 or 3.2.1-2.

2) Using Table 3.2.1-7 or 3.2.1-8, locate the appropriate engine data, and prepare a list of modal emission rates for each mode m and pollutant p:

$$\left(\frac{\Delta e}{\Delta t}\right)_{m,p}$$

3) Using known military assignment and mission, or civil aircraft type and application, use Table 3.2.1-3 or 3.2.1-4 to select an appropriate set of times-in-mode $(TIM)_m$.

4) For each mode m and pollutant p, multiply the modal emission rate and TIM data for each mode and the sum over all modes. This will yield an emission factor per engine, which must be multiplied by the number of engines, N, to produce the emission factor per LTO cycle, E_p, for an aircraft:

$$E_p = N \Sigma \left(\frac{\Delta e}{\Delta t}\right)_{m,p} \cdot (TIM)_m$$

On a conveniently laid out work sheet, this calculation can be set up easily on a hand calculator with one storage location.

Emission factors calculated in exactly this way are presented in Tables 3.2.1-9 and 3.2.1-10.

References for Section 3.2.1

1. D. R. Sears, Air Pollutant Emission Factors for Military and Civil Aircraft, EPA-450/3-78-117, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, October 1978.

2. R. G. Pace, "Technical Support Report - Aircraft Emission Factors", Office of Mobile Source Air Pollution Control, U.S. Environmental Protection Agency, Ann Arbor, MI, March 1977.

3. Control of Air Pollution for Aircraft and Aircraft Engines, 38 FR 19088, July 17, 1973.

4. M. Platt, et al., The Potential Impact of Aircraft Emissions upon Air Quality, APTD-1085, U.S. Environmental Protection Agency, Research Triangle Park, NC, December 1971.

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Emissions from gasoline trucks have been studied by a combination of theoretical and experimental techniques, and typical emission values are presented in Table 4.4-3.[7,8] Emissions depend upon the extent of venting from the tank truck during transit, which in turn depends on the tightness of the truck, the pressure relief valve settings, the pressure in the tank at the start of the trip, the vapor pressure of the fuel being transported, and the degree of saturation (with fuel vapor) of the vapor space in the tank. The emissions are *not* directly proportional to the time spent in transit. As the leakage rate of the truck increases, emissions increase up to a point and then level off as other factors take over in determining the rate. Tank trucks in dedicated vapor balance service typically contain saturated vapors, and this leads to lower emissions during transit, because no additional fuel evaporates to raise the pressure in the tank to cause venting. Table 4.4-3 lists "typical" values for emissions and "extreme" values which could occur in the unlikely event that all determining factors combined to cause maximum emissions.

Table 4.4-3. HYDROCARBON EMISSION FACTORS FOR PETROLEUM LIQUID TRANSPORTATION AND MARKETING SOURCES

Emission source	Product emission factors[a]					
	Gasoline[b]	Crude oil[c]	Jet naphtha (JP-4)	Jet kerosene	Distillate oil No. 2	Residual oil No. 6
Tank cars/trucks						
Submerged loading - normal service						
lb/10³ gal transferred	5	3	1.5	0.02	0.01	0.0001
kg/10³ liters transferred	0.6	0.4	0.18	0.002	0.001	0.00001
Splash loading - normal service						
lb/10³ gal transferred	12	7	4	0.04	0.03	0.0003
kg/10³ liters transferred	1.4	0.8	0.5	0.005	0.004	0.00004
Submerged loading - balance service						
lb/10³ gal transferred	8	5	2.5	d	d	d
kg/10³ liters transferred	1.0	0.6	0.3			
Splash loading - balance service						
lb/10³ gal transferred	8	5	2.5	d	d	d
kg/10³ liters transferred	1.0	0.6	0.3			
Transit - loaded with fuel						
lb/10³ gal transferred	0-0.01 typical	e	e	e	e	e
	0-0.08 extreme	e	e	e	e	e
kg/10³ liters transferred	0-0.001 typical	e	e	e	e	e
	0-0.009 extreme	e	e	e	e	e

Table 4.4-3 (continued). HYDROCARBON EMISSION FACTORS FOR PETROLEUM LIQUID TRANSPORTATION AND MARKETING SOURCES

Emission source	Product emission factors[a]					
	Gasoline[b]	Crude oil[c]	Jet naphtha (JP-4)	Jet kerosene	Distillate oil No. 2	Residual oil No. 6
Transit - return with vapor						
lb/10³ gal transferred	0-0.11 typical	e	e	e	e	e
	0-0.37 extreme	e	e	e	e	e
kg/10³ liters transferred	0-0.013 typical	e	e	e	e	e
	0-0.44 extreme	e	e	e	e	e
Marine vessels						
Loading tankers						
lb/10³ gal transferred	f	0.7	0.5	0.005	0.005	0.00004
kg/10³ liters transferred		0.08	0.06	0.0006	0.0006	5×10^{-6}
Loading barges						
lb/10³ gal transferred	f	1.7	1.2	0.0013	0.012	0.00009
kg/10³ liters transferred	f	0.20	0.14	0.0016	0.0014	1.1×10^{-5}
Tanker ballasting						
lb/10³ gal cargo capacity	0.8	0.6	e	e	e	e
kg/10³ liters cargo capacity	0.10	0.07				
Transit						
lb/week - 10³ gal transported	3	1.0	0.7	0.005	0.005	3×10^{-5}
kg/week - 10³ liters transported	0.4	0.1	0.08	0.0006	0.0006	4×10^{-6}

[a] Emission factors are calculated for dispensed fuel temperature of 60°F.

[b] The example gasoline has an RVP of 10 psia.

[c] The example crude oil has an RVP of 5 psia.

[d] Not normally used.

[e] Not available.

[f] See Table 4.4-2 for these emission factors.

4.4.2.3 Service Stations - Another major source of evaporative hydrocarbon emissions is the filling of underground gasoline storage tanks at service stations. Normally, gasoline is delivered to service stations in large (8000 gallon) tank trucks. Emissions are generated when hydrocarbon vapors in the underground storage tank are displaced to the atmosphere by the gasoline being loaded into the tank. As with other

4.7 WASTE SOLVENT RECLAMATION

4.7.1 Process Description[1-4]

Waste solvents are organic dissolving agents that are contaminated with suspended and dissolved solids, organics, water, other solvents, and/or any substance not added to the solvent during its manufacture. Reclamation is the process of restoring a waste solvent to a condition that permits its reuse, either for its original purpose or for other industrial needs. All waste solvent is not reclaimed, because the cost of reclamation may exceed the value of the recovered solvent.

Industries that produce waste solvents include solvent refining, polymerization processes, vegetable oil extraction, metallurgical operations, pharmaceutical manufacture, surface coating, and cleaning operations (dry cleaning and solvent degreasing). The amount of solvent recovered from the waste varies from about 40 to 99 percent, depending on the extent and characterization of the contamination and on the recovery process employed.

Design parameters and economic factors determine whether solvent reclamation is accomplished as a main process by a private contractor, as an integral part of a main process (such as solvent refining), or as an added process (as in the surface coating and cleaning industries). Most contract solvent reprocessing operations recover halogenated hydrocarbons (e.g., methylene chloride, trichlorotrifluoroethane, and trichloroethylene) from degreasing, and/or aliphatic, aromatic, and naphthenic solvents such as those used in the paint and coatings industry. They may also reclaim small quantities of numerous specialty solvents such as phenols, nitriles, and oils.

The general reclamation scheme for solvent reuse is illustrated in Figure 4.7-1. Industrial operations may not incorporate all of these steps. For instance, initial treatment is necessary only when liquid waste solvents contain dissolved contaminants.

4.7.1.1 Solvent Storage and Handling - Solvents are stored before and after reclamation in containers ranging in size from 55 gallon (0.2 m^3) drums to tanks with capacities of 20,000 gallons (75 m^3) or more. Storage tanks are of fixed or floating roof design. Venting systems prevent solvent vapors from creating excessive pressure or vacuum inside fixed roof tanks.

Handling includes loading waste solvent into process equipment and filling drums and tanks prior to transport and storage. The filling is most often done through submerged or bottom loading.

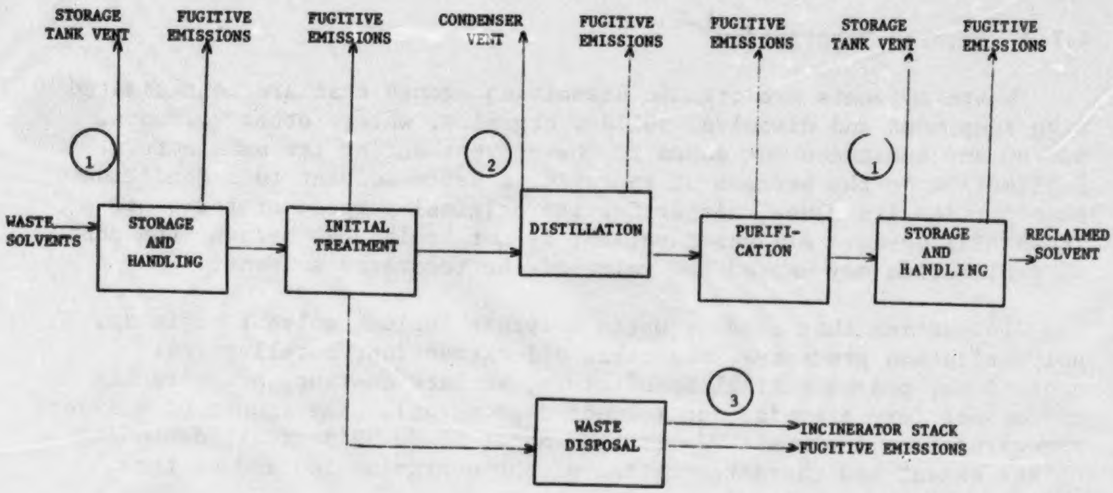
STORAGE TANK VENT
FUGITIVE EMISSIONS
FUGITIVE EMISSIONS
CONDENSER VENT
FUGITIVE EMISSIONS
FUGITIVE EMISSIONS
STORAGE TANK VENT
FUGITIVE EMISSIONS
1
2
1
WASTE SOLVENTS
STORAGE AND HANDLING
INITIAL TREATMENT
DISTILLATION
PURIFI-CATION
STORAGE AND HANDLING
RECLAIMED SOLVENT
3
WASTE DISPOSAL
INCINERATOR STACK
FUGITIVE EMISSIONS

Figure 4.7-1. General waste solvent reclamation scheme and emission points.[1]

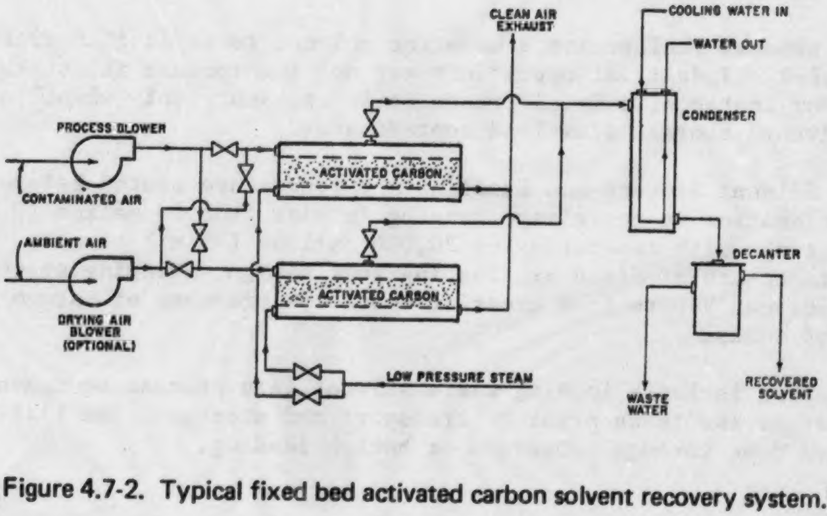
CLEAN AIR EXHAUST
COOLING WATER IN
WATER OUT
CONDENSER
PROCESS BLOWER
ACTIVATED CARBON
CONTAMINATED AIR
AMBIENT AIR
DECANTER
ACTIVATED CARBON
DRYING AIR BLOWER (OPTIONAL)
LOW PRESSURE STEAM
WASTE WATER
RECOVERED SOLVENT

Figure 4.7-2. Typical fixed bed activated carbon solvent recovery system.[6]

Table 4.7-1. EMISSION FACTORS FOR SOLVENT RECLAIMING[a]

EMISSION FACTOR RATING: D

Source	Criteria pollutant	Emission factor average	
		lb/ton	kg/MT
Storage tank vent[b]	Volatile organics	0.02 (0.004-0.09)	0.01 (0.002-0.04)
Condenser vent	Volatile organics	3.30 (0.52-8.34)	1.65 (0.26-4.17)
Incinerator stack[c]	Volatile organics	0.02	0.01
Incinerator stack	Particulates	1.44 (1.1-2.0)	0.72 (0.55-1.0)
Fugitive emissions			
Spillage[c]	Volatile organics	0.20	0.10
Loading	Volatile organics	0.72 (0.00024-1.42)	0.36 (0.00012-0.71)
Leaks	Volatile organics	NA	NA
Open sources	Volatile organics	NA	NA

[a] Reference 1. Data obtained from state air pollution control agencies and presurvey sampling. All emission factors are for uncontrolled process equipment, except those for the incinerator stack. (Reference 1 does not, however, specify what the control is on this stack.) Average factors are derived from the range of data points available. Factors for these sources are given in terms of pounds per ton and kilograms per metric ton of reclaimed solvent. Ranges in parentheses. NA - not available.

[b] Storage tank is of fixed roof design.

[c] Only one value available.

4.7.1.2 Initial Treatment - Waste solvents are initially treated by vapor recovery or mechanical separation. Vapor recovery entails removal of solvent vapors from a gas stream in preparation for further reclaiming operations. In mechanical separation, undissolved solid contaminants are removed from liquid solvents.

Vapor recovery or collection methods employed include condensation, adsorption and absorption. Technical feasibility of the method chosen depends on the solvent's miscibility, vapor composition and concentration, boiling point, reactivity, and solubility, as well as several other factors.

Condensation of solvent vapors is accomplished by water cooled condensers and refrigeration units. For adequate recovery, a solvent vapor concentration well above 0.009 grains per cubic foot (20 mg/m^3) is required. To avoid explosive mixtures of a flammable solvent and air in the process gas stream, air is replaced with an inert gas, such as nitrogen. Solvent vapors that escape condensation are recycled through the main process stream or recovered by adsorption or absorption.

Activated carbon adsorption is the most common method of capturing solvent emissions. Adsorption systems are capable of recovering solvent vapors in concentrations below 0.002 grains per cubic foot (4 mg/m^3) of air. Solvents with boiling points of 290°F (200°C) or more do not desorb effectively with the low pressure steam commonly used to regenerate the carbon beds. Figure 4.7-2 shows a flow diagram of a typical fixed bed activated carbon solvent recovery system. The mixture of steam and solvent vapor passes to a water cooled condenser. Water immiscible solvents are simply decanted to separate the solvent, but water miscible solvents must be distilled, and solvent mixtures must be both decanted and distilled. Fluidized bed operations are also in use.

Absorption of solvent vapors is accomplished by passing the waste gas stream through a liquid in scrubbing towers or spray chambers. Recovery by condensation and adsorption results in a mixture of water and liquid solvent, while absorption recovery results in an oil and solvent mixture. Further reclaiming procedures are required, if solvent vapors are collected by any of these three methods.

Initial treatment of liquid waste solvents is accomplished by mechanical separation methods. This includes both removing water by decanting and removing undissolved solids by filtering, draining, settling, and/or centrifuging. A combination of initial treatment methods may be necessary to prepare waste solvents for further processing.

4.7.1.3 Distillation - After initial treatment, waste solvents are distilled to remove dissolved impurities and to separate solvent mixtures. Separation of dissolved impurities is accomplished by simple batch, simple continuous, or steam distillation. Mixed solvents are separated by multiple simple distillation methods, such as batch or continuous rectification. These processes are shown in Figure 4.7-3.

In simple distillation, waste solvent is charged to an evaporator. Vapors are then continuously removed and condensed, and the resulting sludge or still bottoms are drawn off. In steam distillation, solvents

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are vaporized by direct contact with steam which is injected into the evaporator. Simple batch, continuous, and steam distillations follow Path I in Figure 4.7-3.

The separation of mixed solvents requires multiple simple distillation or rectification. Batch and continuous rectification are represented by Path II in Figure 4.7-3. In batch rectification, solvent vapors pass through a fractionating column, where they contact condensed solvent (reflux) entering at the top of the column. Solvent not returned as reflux is drawn off as overhead product. In continuous rectification, the waste solvent feed enters continuously at an intermediate point in the column. The more volatile solvents are drawn off at the top, while those with higher boiling points collect at the bottom.

Design criteria for evaporating vessels depend on waste solvent composition. Scraped surface stills or agitated thin film evaporators are the most suitable for heat sensitive or viscous materials. Condensation is accomplished by barometric or shell and tube condensers. Azeotropic solvent mixtures are separated by the addition of a third solvent component, while solvents with higher boiling points, e.g., in the range of high flash naphthas (310°F, 155°C), are most effectively distilled under vacuum. Purity requirements for the reclaimed solvent determine the number of distillations, reflux ratios and processing time needed.

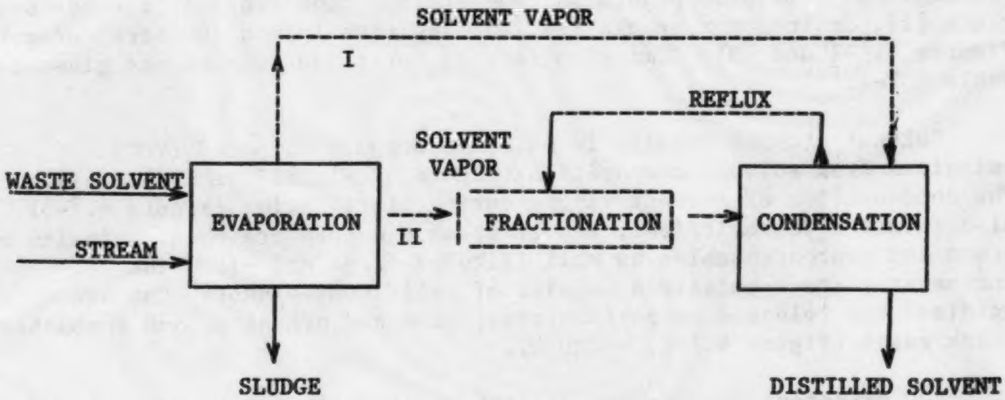

Figure 4.7-3. Distillation process for solvent reclaiming.[1]

4.7.1.4 Purification - After distillation, water is removed from solvent by decanting or salting. Decanting is accomplished with immiscible solvent and water which, when condensed, form separate liquid layers, one or the other of which can be drawn off mechanically. Additional cooling of the solvent/water mix before decanting increases the separation of the two components by reducing their solubility. In salting, solvent is passed through a calcium chloride bed, and water is removed by absorption.

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During purification, reclaimed solvents are stabilized, if necessary. Buffers are added to virgin solvents to ensure that pH level is kept constant during use. To renew it, special additives are used during purification. The composition of these additives is considered proprietary.

4.7.1.5 Waste Disposal - Waste materials separated from solvents during initial treatment and distillation are disposed of by incineration, landfilling or deep well injection. The composition of such waste varies, depending on the original use of the solvent. But up to 50 percent is unreclaimed solvent, which keeps the waste product viscous yet liquid, thus facilitating pumping and handling procedures. The remainder consists of components such as oils, greases, waxes, detergents, pigments, metal fines, dissolved metals, organics, vegetable fibers, and resins.

About 80 percent of the waste from solvent reclaiming by private contractors is disposed of in liquid waste incinerators. About 14 percent is deposited in sanitary landfills, usually in 55 gallon drums. Deep well injection is the pumping of wastes between impermeable geologic strata. Viscous wastes may have to be diluted for pumping into the desired stratum level.

4.7.2 Emissions and Controls[1,3-5]

Volatile organic and particulate emissions result from waste solvent reclamation. Emission points include storage tank vents [1], condenser vents [2], incinerator stacks [3], and fugitive losses (numbers refer to Figures 4.7-1 and -3). Emission factors for these sources are given in Table 4.7-1.

Solvent storage results in volatile organic compound (VOC) emissions from solvent evaporation (Figure 4.7-1, emission point 1). The condensation of solvent vapors during distillation (Figure 4.7-3) also involves VOC emissions, and if steam ejectors are used, emission of steam and noncondensables as well (Figures 4.7-1 and -3, point 2). Incinerator stack emissions consist of solid contaminants that are oxidized and released as particulates, unburned organics, and combustion stack gases (Figure 4.7-1, point 3).

VOC emissions from equipment leaks, open solvent sources (sludge drawoff and storage from distillation and initial treatment operations), solvent loading, and solvent spills are classifed as fugitive. The former two sources are continuously released, and the latter two, intermittently.

Solvent reclamation is viewed by industry as a form of control in itself. Carbon adsorption systems can remove up to 95 percent of the solvent vapors from an air stream. It is estimated that less than 50 percent of reclamation plants run by private contractors use any control technology.

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Volatile organic emissions from the storage of solvents can be reduced by as much as 98 percent by converting from fixed to floating roof tanks, although the exact percent reduction also depends on solvent evaporation rate, ambient temperature, loading rate, and tank capacity. Tanks may also be refrigerated or equipped with conservation vents which prevent air inflow and vapor escape until some preset vacuum or pressure develops.

Solvent vapors vented during distillation are controlled by scrubbers and condensers. Direct flame and catalytic afterburners can also be used to control noncondensables and solvent vapors not condensed during distillation. The time required for complete combustion depends on the flammability of the solvent. Carbon or oil adsorption may be employed also, as in the case of vent gases from the manufacture of vegetable oils.

Wet scrubbers are used to remove particulates from sludge incinerator exhaust gases, although they do not effectively control submicron particles.

Submerged rather than splash filling of storage tanks and tank cars can reduce solvent emissions from this source by more than 50 percent. Proper plant maintenance and loading procedures reduce emissions from leaks and spills. Open solvent sources can be covered to reduce these fugitive emissions.

References for Section 4.7

1. D. R. Tierney and T. W. Hughes, Source Assessment: Reclaiming of Waste Solvents - State of the Art, EPA-600/2-78/004f, U.S. Environmental Protection Agency, Cincinnati, OH, April 1978.

2. J. E. Levin and F. Scofield, "An Assessment of the Solvent Reclaiming Industry". Proceedings of the 170th Meeting of the American Chemical Society, Chicago, IL, 35(2):416-418, August 25-29, 1975.

3. H. M. Rowson, "Design Considerations in Solvent Recovery". Proceedings of the Metropolitan Engineers' Council on Air Resouces (MECAR) Symposium on New Developments in Air Pollutant Control, New York, NY, October 23, 1961, pp. 110-128.

4. J. C. Cooper and F. T. Cuniff, "Control of Solvent Emissions". Proceedings of the Metropolitan Engineers' Council on Air Resources (MECAR) Symposium on New Developments in Air Pollution Control, New York, NY, October 23, 1961, pp. 30-41.

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5. W. R. Meyer, "Solvent Broke", Proceedings of TAPPI Testing Paper Synthetics Conference, Boston, MA, October 7-9, 1974, pp. 109-115.

6. Nathan R. Shaw, "Vapor Adsorption Technology for Recovery of Chlorinated Hydrocarbons and Other Solvents", Presented at the 80th Annual Meeting of the Air Pollution Control Association, Boston, MA, June 15-20, 1975.

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4.8 TANK AND DRUM CLEANING

4.8.1 General

Rail tank cars, tank trucks and drums are used to transport about 700 different commodities. Rail tank cars and most tank trucks and drums are in dedicated service (carrying one commodity only) and, unless contaminated, are cleaned only prior to repair or testing. Nondedicated tank trucks (about 20,000, or 22 percent of the total in service) and drums (approximately 5.6 million, or 12.5 percent of the total) are cleaned after every trip.

4.8.1.1 Rail Tank Cars - Most rail tank cars are privately owned. Some cars, like those owned by the railroads, are operated for hire. The commodities hauled are 35 percent petroleum products, 20 percent organic chemicals, 25 percent inorganic chemicals, 15 percent compressed gases, and 5 percent food products. Petroleum products considered in this study are glycols, vinyls, acetones, benzenes, creosote, etc. Not included in these figures are gasoline, diesel oil, fuel oils, jet fuels, and motor oils, the greatest portion of these being transported in dedicated service.

Much tank car cleaning is conducted at shipping and receiving terminals, where the wastes go to the manufacturers' treatment systems. However, 30 to 40 percent is done at service stations operated by tank car owner/lessors. These installations clean waste of a wide variety of commodities, many of which require special cleaning methods.

A typical tank car cleaning facility cleans 4 to 10 cars per day. Car capacity varies from 10,000 to 34,000 gallons (40 - 130 m^3). Cleaning agents include steam, water, detergents and solvents, which are applied using steam hoses, pressure wands, or rotating spray heads placed through the opening in the top of the car. Scraping of hardened or crystallized products is often necessary. Cars carrying gases and volatile materials, and those needing to be pressure tested, must be filled or flushed with water. The average amount of residual material cleaned from each car is estimated to be 550 lb (250 kg). Vapors from car cleaning not flared or dissolved in water are dissipated to the atmosphere.

4.8.1.2 Tank Trucks - Two thirds of the tank trucks in service in the United States are operated for hire. Of these, 80 percent are used to haul bulk liquids. Most companies operate fleets of five trucks or less, and whenever possible, these trucks are assigned to dedicated service. Commodities hauled and cleaned are 15 percent petroleum products (except as noted in 4.8.1.1), 35 percent organic chemicals, 5 percent food products, and 10 percent other products.

Interior washing is carried out at many tank truck dispatch terminals. Cleaning agents include water, steam, detergents, bases, acids and solvents, which are applied with hand-held pressure wands or by

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Turco or Butterworth rotating spray nozzles. Detergent, acidic or basic solutions are usually used until spent and then sent to treatment facilities. Solvents are recycled in a closed system, with sludges either incinerated or landfilled. The average amount of material cleaned from each trailer is 220 lb (100 kg). Vapors from volatile material are flared at a few terminals but most commonly are dissipated to the atmosphere. Approximately 60 gallons (0.23 m^3) of liquid are used per tank truck steam cleaning and 5500 gallons (20.9 m^3) for full flushing.

Table 4.8-1. EMISSION FACTORS FOR RAIL TANK CAR CLEANING[a]

EMISSION FACTOR RATING: D

Compound	Chemical Class		Total emissions[a]	
	Vapor pressure	Viscosity	lb/car	g/car
Ethylene glycol[b]	low	high	0.0007	0.3
Chlorobenzene[b]	medium	medium	0.0346	15.7
o-Dichlorobenzene[b]	low	medium	0.1662	75.4
Creosote[c]	low	high	5.1808	2350

[a] Reference 1. Emission factors are in terms of average weight of pollutant released per car cleaned.
[b] Two hour test duration.
[c] Eight hour test duration.

4.8.1.3 Drums - Both 55 and 30 gallon (0.2 and 0.11 m^3) drums are used to ship a vast variety of commodities, with organic chemicals (including solvents) accounting for 50 percent. The remaining 50 percent includes inorganic chemicals, asphaltic materials, elastromeric materials, printing inks, paints, food additives, fuel oils and other products.

Drums made entirely of 18 gauge steel have an average life, with total cleaning, of eight trips. Those with 20 gauge bodies and 18 gauge heads have an average life of three trips. Not all drums are cleaned, especially those of thinner construction.

Tighthead drums which have carried materials that are easy to clean are steamed or washed with base. Steam cleaning is done by inserting a nozzle into the drum, with vapors going to the atmosphere. Base washing is done by tumbling the drum with a charge of hot caustic solution and some pieces of chain.

Drums used to carry materials that are difficult to clean are burned out, either in a furnace or in the open. Those with tightheads have the tops cut out and are reconditioned as open head drums. Drum burning furnaces may be batch or continuous. Several gas burners bathe the drum in flame, burning away the contents, lining and outside paint in a nominal 4 minute period and at a temperature of at least 900° but not more than 1000°F (480 - 540°C) to prevent warping of the drum. Emissions are vented to an afterburner or secondary combustion chamber, where the gases are raised to at least 1500°F (760°C) for a minimum of 0.5 seconds. The average amount of material removed from each drum is 4.4 lb (2 kg).

Table 4.8-2. EMISSION FACTORS FOR TANK TRUCK CLEANING[a]

EMISSION FACTOR RATING: D

Compound	Chemical Class: Vapor pressure	Chemical Class: Viscosity	Total emissions: lb/truck	Total emissions: g/truck
Acetone	high	low	0.686	311
Perchloroethylene	high	low	0.474	215
Methyl methacrylate	medium	medium	0.071	32.4
Phenol	low	low	0.012	5.5
Propylene glycol	low	high	0.002	1.07

[a] Reference 1. One hour test duration.

4.8.2 Emissions and Controls

4.8.2.1 Rail Tank Cars and Tank Trucks - Atmospheric emissions from tank car and truck cleaning are predominantly volatile organic chemical vapors. To achieve a practical but representative picture of these emissions, the organic chemicals hauled by the carriers must be broken down into classes of high, medium and low viscosities and high, medium and low vapor pressures. This is because high viscosity materials do not drain readily, affecting the quantity of material remaining in the tank, and high vapor pressure materials volatilize more readily during cleaning and tend to lead to greater emissions.

Practical and economically feasible controls of atmospheric emissions from tank car and truck cleaning do not exist, except for containers transporting commodities that produce combustible gases and water soluble vapors (such as ammonia and chlorine). Gases which are displaced as tanks are filled are sent to a flare and burned. Water soluble vapors are absorbed in water and sent to the wastewater system. Any other emissions are vented to the atmosphere.

Tables 4.8-1 and 4.8-2 give emission factors for representative organic chemicals hauled by tank cars and trucks.

4.8.2.2 Drums - There is no control for emissions from steaming of drums. Solution or caustic washing yields negligible air emissions, because the drum is closed during the wash cycle. Atmospheric emissions from steaming or washing drums are predominantly organic chemical vapors.

Air emissions from drum burning furnaces are controlled by proper operation of the afterburner or secondary combustion chamber, where gases are raised to at least 1500°F (760°C) for a minimum of 0.5 seconds. This normally ensures complete combustion of organic materials and prevents the formation, and subsequent release, of large quantities of NO_x, CO and particulates. In open burning, however, there is no feasible way of controlling the release of incomplete combustion products to the atmosphere. Converting open cleaning operations to closed cycle cleaning and eliminating open air drum burning seem to be the only control alternatives immediately available.

Table 4.8-3 gives emission factors for representative criteria pollutants emitted from drum burning and cleaning.

Table 4.8-3. EMISSION FACTORS FOR DRUM BURNING[a]

EMISSION FACTOR RATING: E

Pollutant	Total Emissions			
	Controlled		Uncontrolled	
	lb/drum	g/drum	lb/drum	g/drum
Particulate	0.02646	12[b]	0.035	16
NO_x	0.00004	0.018	0.002	0.89
VOC	negligible		negligible	

[a] Reference 1. Emission factors are in terms of weight of pollutant released per drum burned, except for VOC, which are per drum washed.

[b] Reference 1, Table 17 and Appendix A.

Reference for Section 4.8

1. T. R. Blackwood, et al., Source Assessment: Rail Tank Car, Tank Truck, and Drum Cleaning, State of the Art, EPA-600/2-78-004g, U.S. Environmental Protection Agency, Research Triangle Park, NC, April 1978.

5.5 CHLOR–ALKALI

5.5.1 Process Description[1]

Chlorine and caustic are produced concurrently by the electrolysis of brine in either the diaphragm or mercury cell. In the diaphragm cell, hydrogen is liberated at the cathode and a diaphragm is used to prevent contact of the chlorine produced at the anode with either the alkali hydroxide formed or the hydrogen. In the mercury cell, liquid mercury is used as the cathode and forms an amalgam with the alkali metal. The amalgam is removed from the cell and is allowed to react with water in a separate chamber, called a denuder, to form the alkali hydroxide and hydrogen.

Chlorine gas leaving the cells is saturated with water vapor and then cooled to condense some of the water. The gas is further dried by direct contact with strong sulfuric acid. The dry chlorine gas is then compressed for in-plant use or is cooled further by refrigeration to liquefy the chlorine.

Caustic as produced in a diaphragm-cell plant leaves the cell as a dilute solution along with unreacted brine. The solution is evaporated to increase the concentration to a range of 50 to 73 percent; evaporation also precipitates most of the residual salt, which is then removed by filtration. In mercury-cell plants, high-purity caustic can be produced in any desired strength and needs no concentration.

5.5.2 Emissions and Controls[1]

Emissions from diaphragm- and mercury-cell chlorine plants include chlorine gas, carbon dioxide, carbon monoxide, and hydrogen. Gaseous chlorine is present in the blow gas from liquefaction, from vents in tank cars and tank containers during loading and unloading, and from storage tanks and process transfer tanks. Other emissions include mercury vapor from mercury cathode cells and chlorine from compressor seals, header seals, and the air blowing of depleted brine in mercury-cell plants.

Chlorine emissions from chlor-alkali plants may be controlled by one of three general methods: (1) use of the gas in other plant processes, (2) neutralization in alkaline scrubbers, and (3) recovery of chlorine from effluent gas streams. The effect of specific control practices is shown to some extent in the table on emission factors (Table 5.5-1).

References for Section 5.5

1. Atmospheric Emissions from Chlor-Alkali Manufacture. U.S. EPA, Air Pollution Control Office. Research Triangle Park, N.C. Publication Number AP-80. January 1971.

2. Duprey, R.L. Compilation of Air Pollutant Emission Factors. U.S. DHEW, PHS, National Center for Air Pollution Control. Durham, N.C. PHS Publication Number 999-AP-42. 1968. p. 49.

Table 5.5-1. EMISSION FACTORS FOR CHLOR-ALKALI PLANTS[a]
EMISSION FACTOR RATING: B

Type of source	Chlorine gas	
	lb/100 tons	kg/100 MT
Liquefaction blow gases		
Diaphragm cell	2,000 to 10,000	1,000 to 5,000
Mercury cell[b]	4,000 to 16,000	2,000 to 8,000
Water absorber[c]	25 to 1,000	12.5 to 500
Caustic or lime scrubber[c]	1	0.5
Loading of chlorine		
Tank car vents	450	225
Storage tank vents	1,200	600
Air blowing of mercury cell brine	500	250

[a] References 1 and 2.
[b] Mercury cells lose about 1.5 pounds mercury per 100 tons (0.75 kg/100 MT) of chlorine liquefied.
[c] Control devices.

5.8 HYDROFLUORIC ACID

5.8.1 Process Description[1-3]

Nearly all of the hydrofluoric acid, or hydrogen fluoride, currently produced in the United States is manufactured by the reaction of acid-grade fluorospar with sulfuric acid in the reaction:

CaF_2	$+ H_2SO_4$	$\longrightarrow$	$CaSO_4$	$+ 2\ HF$
Calcium Fluoride (Fluorospar)	Sulfuric Acid		Calcium Sulfate (Anhydrite)	Hydrogen Fluoride (Hydrofluoric Acid)

The fluorospar typically contains 97.5 percent or more calcium fluoride, 1 percent or less silicon dioxide (SiO_2), and 0.05 percent or less sulfur, with calcium carbonate ($CaCO_3$) as the principal remainder. See Figure 5.8-1 for a typical process flow diagram.

The reaction to produce the acid is endothermic and is usually carried out in externally heated horizontal rotary kilns for 30 to 60 minutes at 390 to 480°F (200-250°C). Dry fluorospar and a slight excess of sulfuric acid are fed continuously to the front end of the kiln. Anhydrite is removed through an air lock at the opposite end. The gaseous reaction products - hydrogen fluoride, excess sulfuric acid from the primary reaction, silicon tetrafluoride, sulfur dioxide, carbon dioxide, and water produced in secondary reactions - are removed from the front end of the kiln with entrained particulate materials. The particulates are removed from the gas stream by a dust separator, and the sulfuric acid and water are removed by a precondenser. The hydrogen fluoride vapors are condensed in refrigerant condensers and are delivered to an intermediate storage tank. The uncondensed gases are passed through a sulfuric acid absorption tower to remove most of the remaining hydrogen fluoride, which is also delivered with the residual sulfuric acid to the intermediate storage tank. The remaining gases are passed through water scrubbers, where the silicon tetrafluoride and remaining hydrogen fluoride are recovered as fluosilicic acid (H_2SiF_6). The hydrogen fluoride and sulfuric acid are delivered to distillation columns, where the hydrofluoric acid is extracted at 99.98 percent purity. Weaker concentrations (typically 70-80 percent) are prepared by dilution with water.

5.8.2 Emissions and Controls[1,2,4]

Air polluting emissions are suppressed to a great extent by the condensing, scrubbing and absorption equipment used in the recovery and purification of the hydrofluoric and fluosilicic acid products. Particulate material in the process gas stream is controlled by a dust separator near the outlet of the kiln and is recycled to the kiln for further

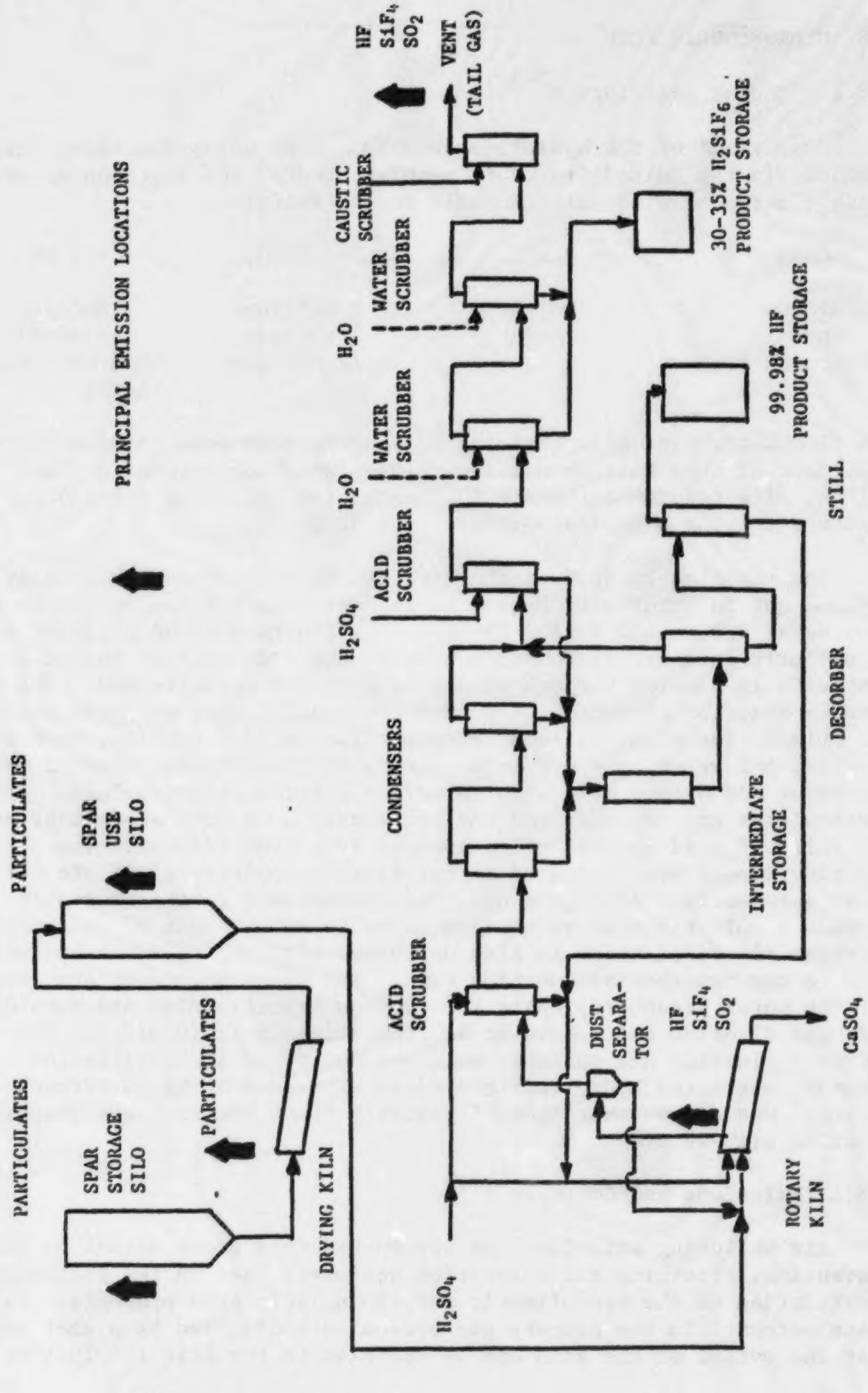
PARTICULATES
SPAR STORAGE SILO
PARTICULATES
DRYING KILN
PARTICULATES
SPAR USE SILO
PRINCIPAL EMISSION LOCATIONS
H_2SO_4
ROTARY KILN
$CaSO_4$
HF
SiF_4
SO_2
DUST SEPARATOR
ACID SCRUBBER
CONDENSERS
INTERMEDIATE STORAGE
DESORBER
H_2SO_4
ACID SCRUBBER
STILL
H_2O
WATER SCRUBBER
99.98% HF PRODUCT STORAGE
H_2O
WATER SCRUBBER
CAUSTIC SCRUBBER
30-35% H_2SiF_6 PRODUCT STORAGE
VENT (TAIL GAS)
HF
SiF_4
SO_2

Figure 5.8-1. Process flow diagram of a typical hydrofluoric acid plant.

Table 5.8-1. EMISSION FACTORS FOR HYDROFLUORIC ACID MANUFACTURE

Type of Operation and Control	Control efficiency (%)	Emissions: Gases: lb/ton acid	Emissions: Gases: kg/MT acid	Emissions: Particulates (Spar): lb/ton Fluorospar	Emissions: Particulates (Spar): kg/MT Fluorospar	Emission Factor Rating
Spar drying[a]						
Uncontrolled	0			75.0	37.5	C
Fabric filter	99			0.8	0.4	
Spar handling silos[b]						
Uncontrolled	0			60.0	30.0	D
Fabric filter	99			0.6	0.3	
Transfer operations						
Uncontrolled	0			6.0	3.0	E
Covers, additives	80			1.2	0.6	
Tail gas[c]						
Uncontrolled	0	25.0 (HF)	12.5 (HF)			
		30.0 (SiF_4)	15.0 (SiF_4)			D
		45.0 (SO_2)	22.5 (SO_2)			
Caustic scrubber	99	0.2 (HF)	0.1 (HF)			
		0.3 (SiF_4)	0.2 (SiF_4)			
		0.5 (SO_2)	0.3 (SO_2)			

[a] Reference 1. Averaged from information provided by four plants. Hourly fluorospar input calculated from reported 1975 year capacity, assuming stoichiometric amount of calcium fluoride and 97.5% content in fluorospar. Hourly emission rates calculated from reported baghouse controlled rates. Values averaged were:

Plant	1975 capacity	Emissions lb/Ton Fluorospar
1	15,000 ton HF	106
2	20,000 ton HF	130
3	50,000 ton HF	42
4	11,000 ton HF	30

[b] Information as in Note a. Four plants averaged for silo emissions, two plants for transfer operations emissions.

[c] Information as in Note a. Three plants averaged. HF and SiF_4 emission factors verified by information in Reference 4.

processing. The precondenser removes water vapor and sulfuric acid mist, and the condenser, acid scrubber and water scrubbers remove all but small amounts of hydrogen fluoride, silicon tetrafluoride, sulfur dioxide and carbon dioxide from the tail gas. A caustic scrubber is employed to reduce further the levels of these pollutants in the tail gas.

Dust emissions result from the handling and drying of the fluorospar, and they are controlled with bag filters at the spar storage silos and drying kilns, their principal emission points.

Hydrogen fluoride emissions are minimized by maintaining a slight negative pressure in the kiln during normal operations. Under upset conditions, a standby caustic scrubber or a bypass to the tail gas caustic scrubber are used to control hydrogen fluoride emissions from the kiln.

Fugitive dust emissions from spar handling and storage are controlled with flexible coverings and chemical additives.

Table 5.8-1 lists the emission factors for the various process operations. The principal emission locations are shown in the process flow diagram, Figure 5.8-1.

References for Section 5.8

1. Screening Study on Feasibility of Standards of Performance for Hydrofluoric Acid Manufacture, EPA-450/3-78-109, U.S. Environmental Protection Agency, Research Triangle Park, NC, October 1978.
2. "Hydrofluoric Acid", Kirk-Othmer Encyclopedia of Chemical Technology, Vol. 9, Interscience Publishers, New York, 1965.
3. W. R. Rogers and K. Muller, "Hydrofluoric Acid Manufacture", Chemical Engineering Progress, 59:5:85-8, May 1963.
4. J. M. Robinson, et al., Engineering and Cost Effectiveness Study of Fluoride Emissions Control, Vol. 1, PB 207 506, National Technical Information Service, Springfield, VA, 1972.

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5.11 PHOSPHORIC ACID

Phosphoric acid is produced by two principal methods, the wet process and the thermal process. The wet process is employed when the acid is to be used for fertilizer production. Thermal process phosphoric acid is of higher purity and is used in the manufacture of high grade chemical and food products.

5.11.1 Process Description[1,2]

5.11.1.1 Wet Process Acid Production - In modern wet process phosphoric acid plants, as shown in Figure 5.11-1, finely ground phosphate rock, which contains 31 to 35.5 percent phosphorus pentoxide (P_2O_5), is continuously fed into a reactor with sulfuric acid which decomposes the phosphate rock. In order to make the strongest phosphoric acid possible and to decrease later evaporation costs, 93 or 98 percent sulfuric acids are normally used. Because the proper ratio of acid to rock in the reactor must be maintained as closely as possible, precise automatic process control equipment is employed in the regulation of these two feed streams.

Gypsum crystals ($CaSO_4 \cdot 2H_2O$) are precipitated by the phosphate rock and sulfuric acid reaction. There is little market for the gypsum, so it is handled as waste, filtered out of the acid and sent to settling ponds. Approximately 0.7 acres of cooling and settling pond are required for every ton of daily P_2O_5 production.

Considerable heat is generated in the reactor, which must be removed. In older plants, this is done by blowing air over the hot slurry surface. Modern plants use vacuum flash cooling of part of the slurry, then sending it back into the reactor.

The reaction slurry is held in the reactor for periods of up to eight hours, depending on the rock and reactor design, and is then sent to be filtered. This produces a 32 percent acid solution, which generally needs concentrating for further use. Current practice is to concentrate it in two or three vacuum evaporators to about 54 percent P_2O_5.

5.11.1.2 Thermal Process Acid Production - Raw materials for the production of phosphoric acid by the thermal process are elemental (yellow) phosphorus, air and water. Thermal process phosphoric acid manufacture, as shown in Figure 5.11-2, typically involves three steps.

First, the liquid elemental phosphorus is burned (oxidized) in a combustion chamber at temperatures of 3000 to 5000°F (1650 - 2760°C) to form phosphorus pentoxide. Then, the phosphorus pentoxide is hydrated with dilute acid or water to produce phosphoric acid liquid and mist. The final step is to remove the phosphoric acid mist from the gas stream.

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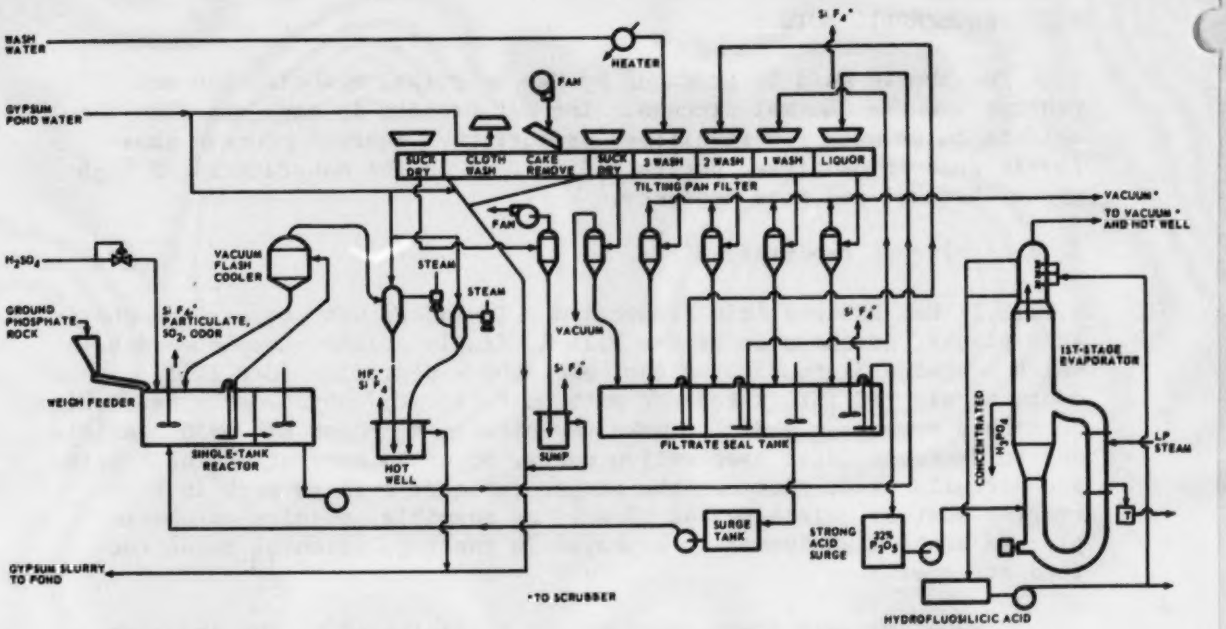
WASH WATER
HEATER
SiF_4*
FAN
GYPSUM POND WATER
SUCK DRY
CLOTH WASH
CAKE REMOVE
SUCK DRY
3 WASH
2 WASH
1 WASH
LIQUOR
TILTING PAN FILTER
VACUUM*
TO VACUUM* AND HOT WELL
FAN
H_2SO_4
VACUUM FLASH COOLER
STEAM
STEAM
GROUND PHOSPHATE ROCK
SiF_4* PARTICULATE, SO_2, ODOR
VACUUM
SiF_4*
1ST-STAGE EVAPORATOR
WEIGH FEEDER
HF,* SiF_4
SiF_4*
CONCENTRATED H_3PO_4
LP STEAM
SINGLE-TANK REACTOR
HOT WELL
SUMP
FILTRATE SEAL TANK
SURGE TANK
STRONG ACID SURGE
32% P_2O_5
T
GYPSUM SLURRY TO POND
*TO SCRUBBER
HYDROFLUOSILICIC ACID

Figure 5.11-1. Flow diagram of wet process phosphoric acid plant.

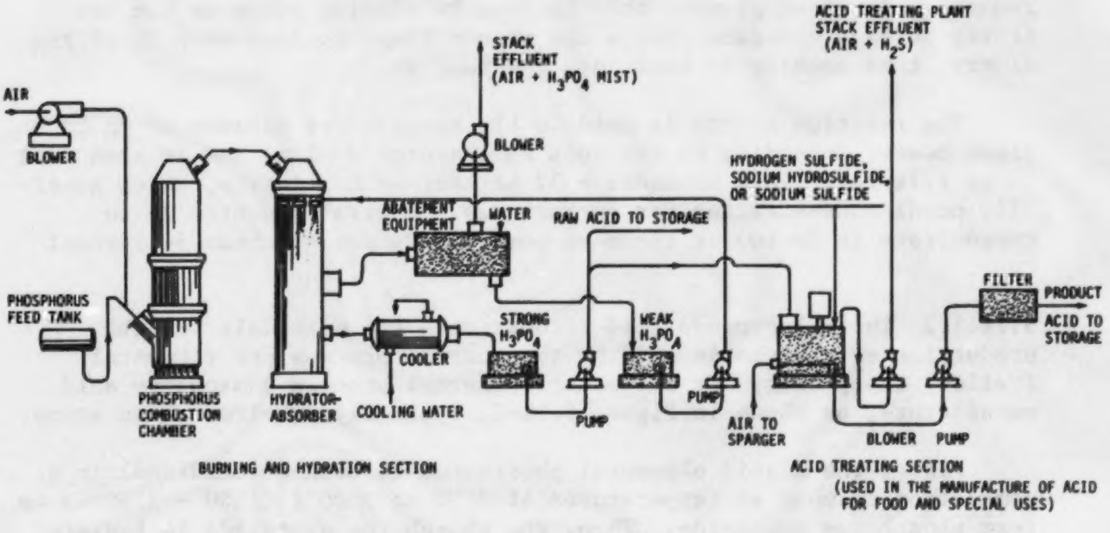
ACID TREATING PLANT STACK EFFLUENT (AIR + H_2S)
STACK EFFLUENT (AIR + H_3PO_4 MIST)
AIR
BLOWER
BLOWER
HYDROGEN SULFIDE, SODIUM HYDROSULFIDE, OR SODIUM SULFIDE
ABATEMENT EQUIPMENT
WATER
RAW ACID TO STORAGE
PHOSPHORUS FEED TANK
FILTER
PRODUCT
ACID TO STORAGE
STRONG H_3PO_4
WEAK H_3PO_4
COOLER
PHOSPHORUS COMBUSTION CHAMBER
HYDRATOR-ABSORBER
COOLING WATER
PUMP
PUMP
AIR TO SPARGER
BLOWER
PUMP
BURNING AND HYDRATION SECTION
ACID TREATING SECTION (USED IN THE MANUFACTURE OF ACID FOR FOOD AND SPECIAL USES)

Figure 5.11-2. Flow diagram of thermal process phosphoric acid plant.

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The reactions involved are:

$$P_4 + 5\ O_2 \rightarrow P_4O_{10}$$

$$P_4O_{10} + 6\ H_2O \rightarrow 4\ H_3PO_4$$

Thermal process acid normally contains 75 to 85 percent phosphoric acid (H_3PO_4). In efficient plants, about 99.9 percent of the phosphorus burned is recovered as acid.

5.11.2 Emissions and Controls[1-3]

5.11.2.1 Wet Process Emissions and Controls - Gaseous fluorides, mostly silicon tetrafluoride and hydrogen fluoride, are the major emissions from wet process acid. Phosphate rock contains 3.5 to 4.0 percent fluorine, and the final distribution of this fluorine in wet process acid manufacture varies widely. In general, part of the fluorine goes with the gypsum, part with the phosphoric acid product, and the rest is vaporized in the reactor or evaporator. The proportions and amounts going with the gypsum and acid depend on the nature of the rock and process conditions. Disposition of the volatilized fluorine depends on the design and operation of the plant. Substantial amounts can pass off into the air, unless effective scrubbers are used. Some of the fluorine which is carried to the settling ponds with the gypsum will get into the atmosphere, once the pond water is saturated with fluorides.

The reactor, where phosphate rock is decomposed by sulfuric acid, is the main source of atmospheric contaminants. Fluoride emissions accompany the air used to cool the reactor slurry. Vacuum flash cooling has replaced the air cooling method to a large extent, since emissions are minimized in the closed system.

Acid concentration by evaporation provides another source of fluoride emissions. It has been estimated that 20 to 40 percent of the fluorine originally present in the rock vaporizes in this operation.

Total particulate emissions directly from process equipment were measured for one digester and for one filter. As much as 11 pounds of particulates per ton of P_2O_5 were produced by the digester, and approximately 0.2 pounds per ton of P_2O_5 were released by the filter. Of this particulate, 3 to 6 percent was fluorides.

Particulate emissions occurring from phosphate rock handling are covered in Section 8.18.

5.11.2.2 Thermal Process Emissions and Controls - The principal atmospheric emission from the thermal process is phosphoric acid mist (H_3PO_4) contained in the gas stream from the hydrator. The particle size of the acid mist ranges from 0.4 to 2.6 micrometers. It is not uncommon for as much as half of the total phosphorus pentoxide to be present as liquid phosphoric acid particles suspended in the gas stream.

Economical operation of the process demands that this potential loss be controlled, so all plants are equipped with some type of emission control equipment.

Control equipment commonly used in thermal process phosphoric acid plants includes venturi scrubbers, cyclonic separators with wire mesh mist eliminators, fiber mist eliminators, high energy wire mesh contactors, and electrostatic precipitators.

Table 5.11-1. EMISSION FACTORS FOR PHOSPHORIC ACID PRODUCTION

EMISSION FACTOR RATING: B

Source	Particulates[a]		Fluorine[b]	
	lb/ton	kg/MT	lb/ton	kg/MT
Wet Process				
Reactor, uncontrolled	-	-	56.4	28.2
Gypsum settling and cooling ponds[c]	-	-	1.12	0.56
Condenser, uncontrolled	-	-	61.2	30.6
Typical controlled emissions[d]	-	-	.02-.07	.01-.04
Thermal Process[e,f]				
Packed tower (95.5%)	2.14	1.07	-	-
Venturi scrubber (97.5%)	2.53	1.27	-	-
Glass fiber mist eliminator (96.0 - 99.9%)	0.69	0.35	-	-
Wire mesh mist eliminator (95.0%)	5.46	2.73	-	-
High pressure drop mist eliminator (99.9%)	0.11	0.06	-	-
Electrostatic precipitator (98 - 99%)	1.66	0.83	-	-

[a] Acid mist particulates (0.4 - 2.6 μm).

[b] References 1 and 3. Pounds of fluorine (as gaseous fluorides) per ton of P_2O_5 produced. Based on a material balance of fluorine from phosphate rock of 3.9% fluorine and 33% P_2O_5.

[c] Approximately 0.7 acres (0.3 hectares) of cooling and settling pond are required to produce 1 ton of P_2O_5 daily. Emissions in terms of pond area would be 1.60 lb/acre per day (1.79 kg/hectare per day).

[d] Reference 5.

[e] Reference 3. Pounds of particulate per ton of P_2O_5.

[f] Numbers in parentheses indicate the control efficiency associated with each device.

References for Section 5.11

1. Atmospheric Emissions from Wet Process Phosphoric Acid Manufacture, AP-57, National Air Pollution Control Administration, Raleigh, NC, April 1970.

2. Atmospheric Emissions from Thermal Process Phosphoric Acid Manufacture, AP-48, National Air Pollution Control Administration, Durham, NC, October 1968.

3. Control Techniques for Fluoride Emissions, Unpublished, U.S. Public Health Service, Research Triangle Park, NC, September 1970.

4. W.R. King, "Fluorine Air Pollution from Wet Process Phosphoric Acid Plants - Water Ponds", Doctoral Thesis, Supported by EPA Research Grant No. R-800950, North Carolina State University, Raleigh, NC, 1974.

5. Final Guideline Document: Control of Fluoride Emissions from Existing Phosphate Fertilizer Plants, EPA-450/2-77-005, U.S. Environmental Protection Agency, Research Triangle Park, NC, March 1977.

5.18 SULFUR RECOVERY

5.18.1 Process Description [1,2]

Most of the elemental sulfur produced from hydrogen sulfide (H_2S) is made by the modified Claus process. A simplified flow diagram of this process is shown in Figure 5.18-1. The process consists of the multistage catalytic oxidation of hydrogen sulfide according to the following overall Reaction:

$$2H_2S + O_2 \rightarrow 2S + 2H_2O \qquad (1)$$

In the first step, one third of the H_2S is reacted with air in a furnace and combusted to SO_2 according to Reaction (2):

$$H_2S + 1.5O_2 \rightarrow SO_2 + H_2O \qquad (2)$$

The heat of the reaction is recovered in a waste heat boiler or sulfur condenser.

For gas streams with low concentrations of H_2S (20 - 60%), approximately one third of the gas stream is fed to the furnace and the H_2S is nearly completely combusted to SO_2, while the remainder of the gas is bypassed around the furnace. This is the "split stream" configuration. For gas streams with higher H_2S concentrations, the entire gas stream is fed to the furnace with just enough air to combust one third of the H_2S to SO_2. This is the "partial combustion" configuration. In this configuration, as much as 50 to 60 percent conversion of the hydrogen sulfide to elemental sulfur takes place in the initial reaction chamber by Reaction (1). In extremely low concentrations of H_2S (<25 - 30%), a Claus process variation known as "sulfur recycle" may be used, where product sulfur is recycled to the furnace and burned, raising the effective sulfur level where flame stability may be maintained in the furnaces.

After the reaction furnace, the gases are cooled to remove elemental sulfur and then reheated. The remaining H_2S in the gas stream is then reacted with the SO_2 over a bauxite catalyst at 500 - 600°F (260 - 316°C) to produce elemental sulfur according to Reaction 3:

$$2H_2S + SO_2 \rightleftarrows 3S + 2H_2O \qquad (3)$$

Because this is a reversible reaction, equilibrium requirements limit the conversion. Lower temperatures favor elemental sulfur formation, but at too low a temperature, elemental sulfur fouls the catalyst. Because the reaction is exothermic, the conversion attainable in one stage is limited. Therefore, two or more stages are used in series, with interstage cooling to remove the heat of reaction and to condense the sulfur.

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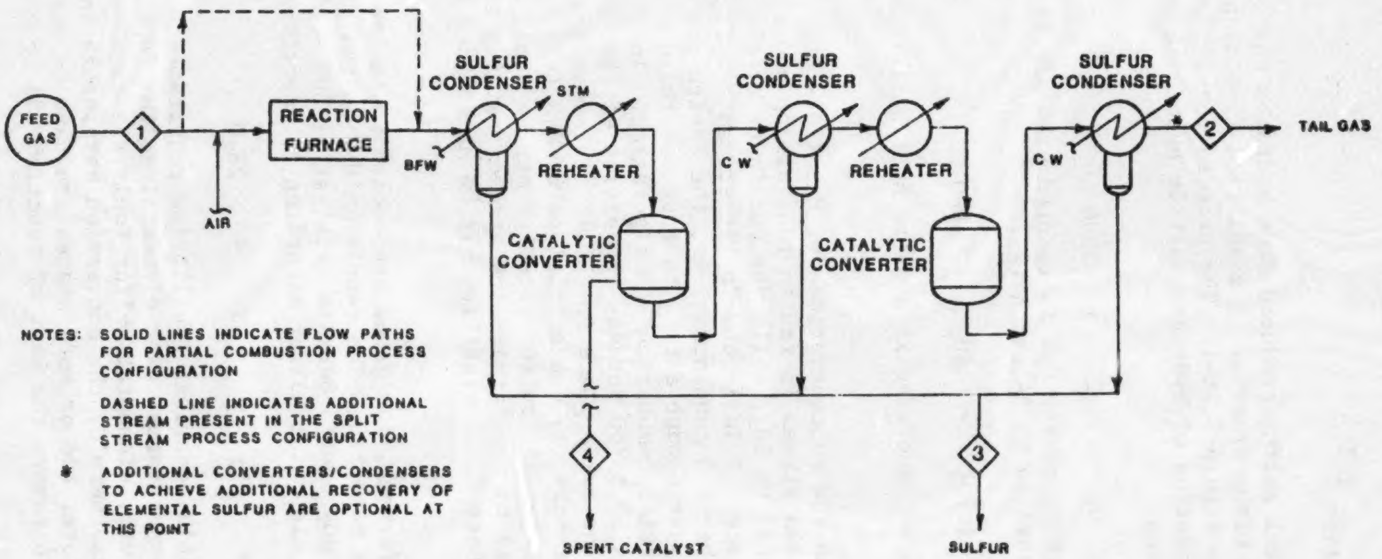
FEED GAS
1
AIR
REACTION FURNACE
SULFUR CONDENSER
BFW
STM
REHEATER
CATALYTIC CONVERTER
SULFUR CONDENSER
C W
REHEATER
CATALYTIC CONVERTER
SULFUR CONDENSER
C W
*
2
TAIL GAS
4
SPENT CATALYST
3
SULFUR

NOTES: SOLID LINES INDICATE FLOW PATHS FOR PARTIAL COMBUSTION PROCESS CONFIGURATION

DASHED LINE INDICATES ADDITIONAL STREAM PRESENT IN THE SPLIT STREAM PROCESS CONFIGURATION

* ADDITIONAL CONVERTERS/CONDENSERS TO ACHIEVE ADDITIONAL RECOVERY OF ELEMENTAL SULFUR ARE OPTIONAL AT THIS POINT

Figure 5.18-1. Typical flow diagram - Claus Process sulfur recovery.

Carbonyl sulfide (COS) and carbon disulfide (CS_2) are formed in the reaction furnace in the presence of carbon dioxide and hydrocarbons:

$$CO_2 + H_2S \rightleftarrows H_2O + COS \qquad (4)$$

$$COS + H_2S \rightleftarrows H_2O + CS_2 \qquad (5)$$

$$CH_4 + 4S \rightleftarrows CS_2 + 2H_2S \qquad (6)$$

About 0.25 to 2.5 percent of the sulfur fed may be lost in this way. Additional sulfur may be lost as vapor, mist or droplets.

5.18.2 Emissions and Controls

Tail gas from a Claus sulfur recovery unit contains a variety of pollutants, including sulfur dioxide, hydrogen sulfide, other reduced sulfur compounds (such as COS and CS_2), carbon monoxide, and volatile organic compounds. If no other controls are used, the tail gas is incinerated, so that the emissions consist mostly of sulfur dioxide. Smaller amounts of carbon monoxide are also emitted.

The emissions of SO_2 (along with H_2S and sulfur vapor) depend directly on the sulfur recovery efficiency of the Claus plant. This efficiency is dependent upon many factors, including the following:

- Number of catalytic conversion stages
- Inlet feed stream composition
- Operating temperatures and catalyst maintenance
- Maintenance of the proper stoichiometric ratio of H_2S/SO_2
- Operating capacity factor

Recovery efficiency increases with the number of catalytic stages used. For example, for a Claus plant fed with 90 percent H_2S, sulfur recovery is approximately 85 percent for one catalytic stage and 95 percent for two or three stages.

Recovery efficiency also depends on the inlet feed stream composition. Sulfur recovery increases with increasing H_2S concentration in the feed stream. For example, a plant having two or three catalytic stages would have a sulfur recovery efficiency of approximately 90 percent when treating a 15 mole percent H_2S feed stream, 93 percent for a 50 mole percent H_2S stream, and 95 percent for a 90 mole percent H_2S stream. Various contaminants in the feed gas reduce Claus sulfur recovery efficiency. Organic compounds in the feed require extra air for combustion, and added water and inert gas from burning these organics decrease sulfur concentrations and thus lower sulfur recovery. Higher molecular weight organics also reduce efficiencies because of soot formation on the catalyst. High concentrations of CO_2 in the feed gas reduce catalyst life.

Since the Claus reactions are exothermic, sulfur recovery is enhanced by removing heat and operating the reactors at as low a temperature as practicable without condensing sulfur on the catalyst. Recovery efficiency also depends on catalyst performance. One to 2 percent loss in recovery efficiency over the period of catalyst life has been reported. Maintenance of the 2:1 stoichiometric ratio of H_2S and SO_2 is essential for efficient sulfur recovery. Deviation above or below this ratio results in a loss of efficiency. Operation of a Claus plant below capacity may also impair Claus efficiency somewhat.

Removal of sulfur compounds from Claus plant tail gas is possible by three general schemes:

1) Extension of the Claus reaction to increase overall sulfur recovery,

2) Conversion of sulfur gases to SO_2, followed by SO_2 removal technology,

3) Conversion of sulfur gases to H_2S, followed by H_2S removal technology.

Processes in the first scheme remove additional sulfur compounds by carrying out the Claus reaction at lower temperatures to shift equilibrium of the Claus reactions toward formation of additional sulfur. The IFP-1, BSR/Selectox, Sulfreen, and Amoco CBA processes use this technique to reduce the concentration of tail gas sulfur compounds to 1500 - 2500 ppm, thus increasing the sulfur recovery of the Claus plant to 99 percent.

In the second class of processes, the tail gas is incinerated to convert all sulfur compounds to SO_2. The SO_2 is then recovered by one of several processes, such as the Wellman-Lord. In the Wellman-Lord and certain other processes, the SO_2 absorbed from the tail gas is recycled to the Claus plant to recover additional sulfur. Processes in this class can reduce the concentration of sulfur compounds in the tail gas to 200 - 300 ppm or less, for an overall sulfur recovery efficiency (including the Claus plant) of 99.9+ percent.

The third method for removal of sulfur compounds from Claus tail gas involves converting the sulfur compounds to H_2S by mixing the tail gas with a reducing gas and passing it over a reducing catalyst. The H_2S is then removed, by the Stretford process (in the Beavon and Clean Air processes) or by an amine absorption system (SCOT process). The Beavon and Clean Air processes recover the H_2S as elemental sulfur, and the SCOT process produces a concentrated H_2S stream which is recycled to the Claus process. These processes reduce the concentration of sulfur compounds in the tail gas to 200 - 300 ppm or less and increase the overall recovery efficiency of the Claus plant to 99.9+ percent.

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A New Source Performance Standard for Claus sulfur recovery plants in petroleum refineries was promulgated in March 1978. This standard limits emissions to 0.025 percent by volume (250 ppm) of SO_2 on a dry basis and at zero percent oxygen, or 0.001 percent by volume of H_2S and 0.03 percent by volume of H_2S, COS, and CS_2 on a dry basis and at zero percent oxygen.

Table 5.18-1. EMISSION FACTORS FOR MODIFIED CLAUS SULFUR RECOVERY PLANTS

EMISSION FACTOR RATING: D

Number of Catalytic Stages	Typical Recovery of Sulfur, %[a]	SO_2 Emissions[b]	
		lb/ton	kg/MT
Two, uncontrolled	92 to 95	348 to 211	174 to 105
Three, uncontrolled	95 to 97.5	211 to 167	106 to 84
Four, uncontrolled	96 to 99	167 to 124	84 to 62
Controlled[c]	99 to 99.9	40 to 4	20 to 2

[a] Efficiencies are for feed gas streams with high H_2S concentrations. Gases with lower H_2S concentrations would have lower efficiencies. For example, a 2 or 3 stage plant could have a recovery efficiency of 95% for a 90% H_2S stream, 93% for 50% H_2S, and 90% for 15% H_2S.

[b] Based on net weight of pure sulfur produced. The range in emission factors corresponds to the range in percentage recovery of sulfur. SO_2 emissions calculated from percentage sulfur recovery by following equation:

$$SO_2 \text{ emissions (kg/MT)} = \frac{(100-\%\text{ recovery})}{\%\text{ recovery}} \times 2000$$

[c] Lower percent recovery is for control by extended Claus, and higher percent is for conversion to and removal of H_2S or SO_2.

References for Section 5.18

1. E. C. Cavanaugh, et al., Environmental Assessment Data Base for Low/Medium Btu Gasification Technology, Volume II, EPA Contract No. 68-02-2147, Radian Corporation, Austin, TX, September 1977.

2. Standards Support and Environmental Impact Statement, Volume 1: Proposed Standards of Performance for Petroleum Refinery Sulfur Recovery Plants. EPA-450/2-76-016a, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1976.

3. B. Goar and T. Arrington, "Guidelines for Handling Sour Gas", Oil and Gas Journal, 76(26): 160-164, June 26, 1978.

6.5 FERMENTATION

6.5.1 Process Description[1]

For the purpose of this report only the fermentation industries associated with food will be considered. This includes the production of beer, whiskey, and wine.

The manufacturing process for each of these is similar. The four main brewing production stages and their respective sub-stages are: (1) brewhouse operations, which include (a) malting of the barley, (b) addition of adjuncts (corn, grits, and rice) to barley mash, (c) conversion of starch in barley and adjuncts to maltose sugar by enzymatic processes, (d) separation of wort from grain by straining, and (e) hopping and boiling of the wort; (2) fermentation, which includes (a) cooling of the wort, (b) additional yeast cultures, (c) fermentation for 7 to 10 days, (d) removal of settled yeast, and (e) filtration and carbonation; (3) aging, which lasts from 1 to 2 months under refrigeration; and (4) packaging, which includes (a) bottling-pasteurization, and (b) racking draft beer.

The major differences between beer production and whiskey production are the purification and distillation necessary to obtain distilled liquors and the longer period of aging. The primary difference between wine making and beer making is that grapes are used as the initial raw material in wine rather than grains.

6.5.2 Emissions[1]

Emissions from fermentation processes are nearly all gases and primarily consist of carbon dioxide, hydrogen, oxygen, and water vapor, none of which present an air pollution problem. Emissions of particulates, however, can occur in the handling of the grain for the manufacture of beer and whiskey. Gaseous hydrocarbons are also emitted from the drying of spent grains and yeast in beer and from the whiskey-aging warehouses. No significant emissions have been reported for the production of wine. Emission factors for the various operations associated with beer, wine, and whiskey production are shown in Table 6.5-1.

As the following Subsection 6.5.2, Wine Making, implies, the FERMENTATION Section is being expanded as new information is obtained.

Except for the Wine Making information, Table 6.5-1 remains valid until further notice.

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Table 6.5-1. EMISSION FACTORS FOR FERMENTATION PROCESSES
EMISSION FACTOR RATING: E

Type of product	Particulates		Hydrocarbons	
	lb/ton	kg/MT	lb/ton	kg/MT
Beer				
Grain handling[a]	3	1.5	–	–
Drying spent grains, etc.[a]	5	2.5	NA[b]	NA
Whiskey				
Grain handling[a]	3	1.5	–	–
Drying spent grains, etc.[a]	5	2.5	NA	NA
Aging	–	–	10[c]	0.024[d]
Wine				

[a] Based on section on grain processing.
[b] No emission factor available, but emissions do occur.
[c] Pounds per year per barrel of whiskey stored.[2]
[d] Kilograms per year per liter of whiskey stored.
[e] No significant emissions.

References for Section 6.5

1. Air Pollutant Emission Factors. Final Report. Resources Research, Inc. Reston, Va. Prepared for National Air Pollution Control Administration, Durham, N.C., under Contract Number CPA-22-69-119. April 1970.

2. Shreve, R.N. Chemical Process Industries, 3rd Ed. New York, McGraw-Hill Book Company. 1967. p. 591-608.

6.5.2 WINE MAKING

6.5.2.1 General[1-4]

Wine is made by the fermentation of the juice of certain fruits, chiefly grapes. The grapes are harvested when the sugar content is right for the desired product, generally around 20 percent sugar by weight. The industry term for grape sugar content is Degrees Brix, with 1 °Brix equal to 1 gram of sugar per 100 grams of juice.

The harvested grapes are stemmed and crushed, and the juice is extracted. Sulfurous acid, potassium metabisulfite or liquefied SO_2 is used to produce 50 to 200 mg of SO_2, which is added to inhibit the growth of undesirable bacteria and yeasts. For the making of a white wine, the skins and solids are removed from the juice before fermentation. For a red wine, the skins and solids, which color the wine, are left in the juice through the fermentation stage. The pulpy mixture of juice, skins and solids is called a "must".

White wine is generally fermented at about 52°F (11°C), and red wine at about 80°F (27°C). Fermentation takes a week to ten days for white wine and about two weeks for red. Fermentation is conducted in tanks ranging in size from several thousand gallons to larger than 500,000 gallons.

The sugar of the fruit juice is converted into ethanol by the reaction:

$$\underset{\text{(sugar)}}{C_6H_{12}O_6} \rightarrow \underset{\text{(ethanol)}}{2\ C_2H_5OH} + 2\ CO_2$$

This process takes place in the presence of a specially cultivated yeast. Theoretically, the yield of ethanol should be 51.1 percent by weight of the initial sugar. The actual yield is found to be around 47 percent. The remaining sugar is lost as alcohol or byproducts of complex chemical mechanisms, or it remains in the wine as the result of incomplete fermentation.

When fermentation is complete, the wine goes through a finishing process for clarification. Common clarification procedures are filtration, fining refrigeration, pasteurization and aging. The wine is then bottled, corked or capped, labeled and cased. The finer red and white table wines are aged in the bottle.

6.5.2.2 Emissions and Controls[1,2]

Large amounts of CO_2 gas are liberated by the fermentation process. The gas is passed into the atmosphere through a vent in the top of the tank. Ethanol losses occur chiefly as a result of entrainment in the

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CO_2. Factors which affect the amount of ethanol lost during fermentation are temperature of fermentation, initial sugar content, and whether a juice or a must is being fermented (i.e., a white or red wine being made).

Emission factors for wine making are given in Table 6.5.2-1. These emission factors are for juice fermentation (white wine) with an initial sugar content of 20 °Brix. Emission factors are given for two temperatures commonly used for fermentation.

Table 6.5.2-1. ETHANOL EMISSION FACTORS FOR UNCONTROLLED WINE FERMENTATION

EMISSION FACTOR RATING: B

Fermentation temperature	Ethanol Emissions[a,b] lb/10^3 gal fermented	 g/kl fermented
52°F (11.1°C)[c]	1.06	127.03
80°F (26.7°C)[c,d]	4.79	574.04
Other conditions	e	e

[a] Due primarily to entrainment in CO_2, not evaporation. H_2S, mercaptans and other componments may be emitted in limited quantities, but no test or other information is available.

[b] C_2H_5OH lost in production.

[c] References 1 and 2. For white wine with initial 20° Brix.

[d] For red wine, add correction term for must fermentation (2.4 lb/10^3 gal or 287.62 g/kl).

[e] See Equation 1.

Emission factors for wines produced under other conditions can be approximated with the following equation:

$$EF = [0.136T - 5.91] + [(B - 20.4)(T - 15.21)(0.00685)] + [C] \qquad (1)$$

where: EF = emission factor, pounds of ethanol lost per thousand gallons of wine made

T = fermentation temperature, °F

B = initial sugar content, °Brix

C = correction term, 0 (zero) for white wine or 2.4 lb/10^3 gal for red wine

Although no testing has been done on emissions from wine fermentation without grapes, it is expected that ethanol is also emitted from these operations.

There is potential alcohol loss at various working and storage stages in the production process. Also, fugitive alcohol emissions could occur from disposal of fermentation solids. Ethanol is considered to be a reactive precursor of photochemical oxidants (ozone). Emissions would be highest during the middle of the fermentation season and would taper off towards the end. Since wine facilities are concentrated in certain areas, these areas would be more affected.

Currently, the wine industry uses no means to control the ethanol lost during fermentation.

References for Section 6.5.2

1. Source Test Report and Evaluation on Emissions from a Fermentation Tank at E. & J. Gallo Winery, C-8-050, California Air Resources Board, Sacramento, CA, October 31, 1978.

2. H. W. Zimmerman, *et al.*, "Alcohol Losses from Entrainment in Carbon Dioxide Evolved during Fermentation", *American Journal of Enology*, *15*:63-68, 1964.

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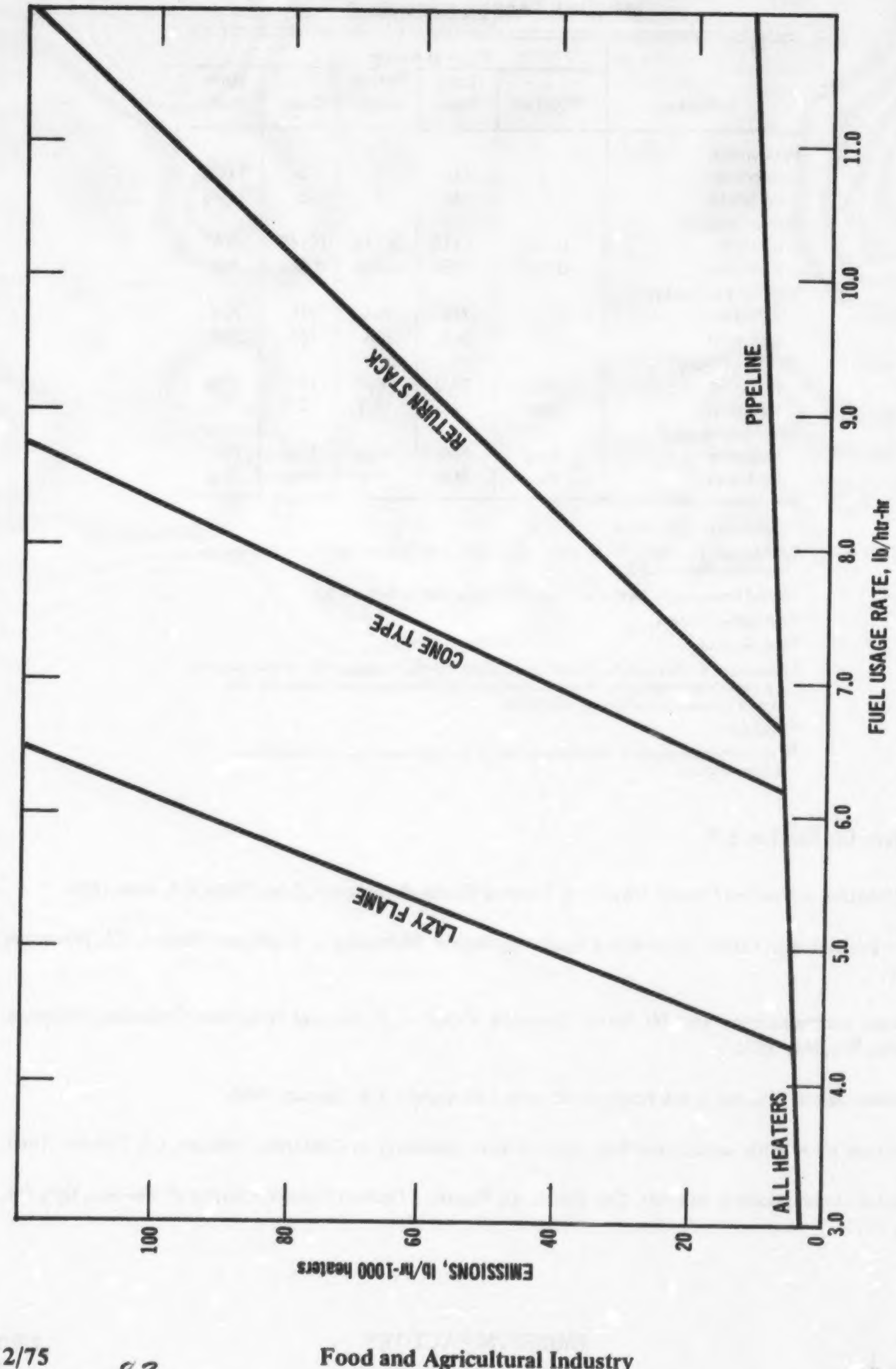

Figure 6.9-2. Particulate emissions from orchard heaters.3,6

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Table 6.9-1. EMISSION FACTORS FOR ORCHARD HEATERS[a]
EMISSION FACTOR RATING: C

Pollutant	Type of heater				
	Pipeline	Lazy flame	Return stack	Cone	Solid fuel
Particulate					
lb/htr-hr	b	b	b	b	0.05
kg/htr-hr	b	b	b	b	0.023
Sulfur oxides[c]					
lb/htr-hr	0.13S[d]	0.11S	0.14S	0.14S	NA[e]
kg/htr-hr	0.06S	0.05S	0.06S	0.06S	NA
Carbon monoxide					
lb/htr-hr	6.2	NA	NA	NA	NA
kg/htr-hr	2.8	NA	NA	NA	NA
Hydrocarbons[f]					
lb/htr-yr	Neg[g]	16.0	16.0	16.0	Neg
kg/htr-yr	Neg	7.3	7.3	7.3	Neg
Nitrogen oxides[h]					
lb/htr-hr	Neg	Neg	Neg	Neg	Neg
kg/htr-hr	Neg	Neg	Neg	Neg	Neg

[a] References 1,3,4, and 6.

[b] Particulate emissions for pipeline, lazy flame, return stack, and cone heaters are shown in Figure 6.9-2.

[c] Based on emission factors for fuel oil combustion in Section 1.3.

[d] S = sulfur content.

[e] Not available.

[f] Reference 1. Evaporative losses only. Hydrocarbon emissions from combustion are considered negligible. Evaporative hydrocarbon losses for units that are part of a pipeline system are negligible.

[g] Negligible.

[h] Little nitrogen oxide is formed because of the relatively low combustion temperatures.

References for Section 6.9

1. Air Pollution in Ventura County. County of Ventura Health Department, Santa Paula, CA, June 1966.
2. Frost Protection in Citrus. Agricultural Extension Service, University of California, Ventura, CA, November 1967.
3. Personal communication with Mr. Wesley Snowden. Valentine, Fisher, and Tomlinson, Consulting Engineers, Seattle, WA, May 1971.
4. Communication with the Smith Energy Company, Los Angeles, CA, January 1968.
5. Communication with Agricultural Extension Service, University of California, Ventura, CA, October 1969.
6. Personal communication with Mr. Ted Wakai. Air Pollution Control District, County of Ventura, Ojai, CA, May 1972.

6.17 HARVESTING OF GRAIN

6.17.1 General[1]

Harvesting of grain refers to the activities performed to obtain the cereal kernels of the plant for grain or the entire plant for forage and/or silage uses. These activities are accomplished by machines that cut, thresh, screen, clean, bind, pick, and shell the crops in the field. Harvesting also includes loading harvested crops into trucks and transporting crops on the grain field.

Crops harvested for their cereal kernels are cut as close as possible to the inflorescence (the flowering portion containing the kernels). This portion is threshed, screened and cleaned to separate the kernels. The grain is stored in the harvest machine while the remainder of the plant is discharged back onto the field.

Combines perform all of the above activities in one operation. Binder machines only cut the grain plants and tie them into bundles or leave them in a row in the field (called a windrow). The bundles are allowed to dry for threshing later by a combine with a pickup attachment.

Corn harvesting requires the only exception to the above procedures. Corn is harvested by mechanical pickers, picker/shellers, and combines with corn head attachments. These machines cut and husk the ears from the standing stalk. The sheller unit also removes the kernels from the ear. After husking, a binder is sometimes used to bundle entire plants into piles (called shocks) to dry.

For forage and/or silage, mowers, crushers, windrowers, field choppers, binders, and similar cutting machines are used to harvest grasses, stalks and cereal kernels. These machines cut the plants as close to the ground as possible and leave them in a windrow. The plants are later picked up and tied by a baler.

Harvested crops are loaded onto trucks in the field. Grain kernels are loaded through a spout from the combine, and forage and silage bales are manually or mechanically placed in the trucks. The harvested crop is then transported from the field to a storage facility.

6.17.2 Emissions and Controls[1]

Emissions are generated by three grain harvesting operations, (1) crop handling by the harvest machine, (2) loading of the harvested crop into trucks, and (3) transport by trucks on the field. Particulate matter, composed of soil dust and plant tissue fragments (chaff) may be entrained by wind. Particulate emissions from these operations ($<7 \mu m$ mean aerodynamic diameter) are developed in Reference 1. For this study, collection stations with air samplers were located downwind (leeward) from the harvesting operations, and dust concentrations were measured at the visible plume centerline and at a constant distance behind the combines. For product loading, since the trailer is stationary while being loaded, it was necessary only to take measurements a fixed distance downwind from the trailer while the plume or puff passed over. The concentration measured for harvesting and loading was applied to a point source atmospheric diffusion model to calculate the source emission rate. For field transport, the air samplers were again placed a fixed distance downwind from the path of the truck, but this time the concentration measured was applied to a line source diffusion model. Readings taken upwind of all field activity gave background concentrations. Particulate emission factors for wheat and sorghum harvesting operations are shown in Table 6.17-1.

There are no control techniques specifically implemented for the reduction of air pollution emissions from grain harvesting. However, several practices and occurences do affect emission rates and concentration. The use of terraces, contouring, and stripcropping to inhibit soil erosion will suppress the entrainment of harvested crop fragments in the wind. Shelterbelts, positioned perpendicular to the prevailing wind, will lower emissions by reducing the wind velocity across the field. By minimizing tillage and avoiding residue burning, the soil will remain consolidated and less prone to disturbance from transport activities.

Table 6.17-1. EMISSION RATES/FACTORS FROM THE HARVESTING GRAIN[a]

EMISSION FACTOR RATING: D

	Emission rate[b]				Emission factor[c]			
	Wheat		Sorghum		Wheat		Sorghum	
Operation	lb/hr	mg/sec	lb/hr	mg/sec	lb/mi^2	g/km^2	lb/mi^2	g/km^2
Harvest machine	0.027	3.4	0.18	23.0	0.96	170.0	6.5	1100.0
Truck loading	0.014	1.8	0.014	1.8	0.07	12.0	0.13	22.0
Field transport	0.37	47.0	0.37	47.0	0.65	110.0	1.2	200.0

[a] Reference 1.

[b] Assumptions from Reference 1 are an average combine speed of 3.36 meters per second, combine swath width of 6.07 meters, and a field transport speed of 4.48 meters per second.

[c] In addition to Note b, assumptions are a truck loading time of six minutes, a truck capacity of .052 km^2 for wheat and .029 km^2 for sorghum, and a filed truck travel time of 125 seconds per load.

Reference for Section 1.14

1. R. A. Wachten and T. R. Blackwood, Source Assessment: Harvesting of Grain, State of the Art, EPA-600/2-79-107f, U. S. Environmental Protection Agency, Research Triangle Park, NC, July 1977.

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7.6 PRIMARY LEAD SMELTING

7.6.1 Process Description[1-3]

Lead is usually found naturally as a sulfide ore containing small amounts of copper, iron, zinc and other trace elements. It is normally concentrated at the mine from an ore of 3 to 8 percent lead to an ore concentrate of 55 to 70 percent lead, containing from 13 to 19 percent, by weight, free and uncombined sulfur. A typical flow sheet for the production of lead metal from ore concentrate is shown in Figure 7.6-1.

Processing involves three major steps:

- Sintering, in which the concentrated lead and sulfur are oxidized to produce lead oxide and sulfur dioxide. (Simultaneously, the charge concentrates, recycled sinter, sand and other inert materials are agglomerated to form a dense, permeable substance called sinter.)

- Reducing the lead oxide contained in the sinter to produce molten lead bullion.

- Refining the lead bullion to eliminate any impurities.

7.6.1.1 Sintering - Sinter is produced by a sinter machine, a continuous steel pallet conveyor belt moved by gears and sprockets. Each pallet consists of perforated or slotted grates, beneath which are windboxes connected to fans that provide a draft through the moving sinter charge. Depending on the direction of this draft, the sinter machine is either of the updraft or downdraft type. Except for the draft direction, however, all machines are similar in design, construction and operation.

The sintering reaction is autogenous, occuring at a temperature of approximately 1800°F (1000°C):

$$2PbS + 3O_2 \rightarrow 2PbO + 2SO_2 \qquad (1)$$

Operating experience has shown that system operation and product quality are optimum when the sulfur content of the sinter charge is between 5 and 7 percent by weight. To maintain this desired sulfur content, sulfide-free fluxes such as silica and limestone, plus large amounts of recycled sinter and smelter residues, are added to the mix. The quality of the product sinter is usually determined by its Ritter Index hardness, which is inversely proportional to the sulfur content. Hard quality sinter (low sulfur content) is preferred, because it resists crushing during discharge from the sinter machine. Undersized sinter usually results from insufficient desulfurization and is recycled for further processing.

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Of the two kinds of sintering machines used, the updraft design is superior for many reasons. First, the sinter bed thickness is more permeable (and hence can be larger), thereby permitting a higher production rate than that of a downdraft machine of similar dimensions. Secondly, the small amounts of elemental lead that form during sintering will solidify at their point of formation in updraft machines, whereas, in downdraft operation, the metal tends to flow downward and collect on the grates or at the bottom of the sinter charge, thus causing increased pressure drop and attendant reduced blower capacity. In addition, the updraft system exhibits the capability of producing sinter of higher lead content and requires less maintenance than the downdraft machine. Finally, and most important from an air pollution control standpoint, updraft sintering can produce a single strong SO_2 effluent stream from the operation, by use of weak gas recirculation. This, in turn, permits more efficient and economical use of control methods such as sulfuric acid recovery devices.

7.6.1.2 Reduction - Lead reduction is carried out in a blast furnace, basically a water jacketed shaft furnace supported by a refractory base. Tuyeres, through which combustion air is admitted under pressure, are located near the bottom and are evenly spaced on either side of the furnace.

The furnace is charged with a mixture of sinter (80 - 90 percent of charge), metallurgical coke (8 - 14 percent of charge), and other materials, such as limestone, silica, litharge, slag-forming constituents, and various recycled and cleanup materials. In the furnace, the sinter is reduced to lead bullion by reactions (2) through (6).

$$PbO + CO \rightarrow Pb + CO_2 \qquad (2)$$

$$C + O_2 \rightarrow CO_2 \qquad (3)$$

$$C + CO_2 \rightarrow 2CO \qquad (4)$$

$$2PbO + PbS \rightarrow 3Pb + SO_2 \qquad (5)$$

$$PbSO_4 + PbS \rightarrow 2Pb + 2SO_2 \qquad (6)$$

Carbon monoxide and heat required for reduction are supplied by the combustion of coke. Most of the impurities are eliminated in the slag. Solid products from the blast furnace generally separate into four layers: speiss, the lightest material (basically arsenic and antimony), matte (copper sulfide and other metal sulfides), slag (primarily silicates), and lead bullion. The first three layers are combined as slag, which is continually collected from the furnace and either processed at the smelter for its metal content or shipped to treatment facilities.

Sulfur oxides are also generated in blast furnaces from small quantities of residual lead sulfide and lead sulfates in the sinter feed. The quantity of these emissions is a function not only of the residual sulfur content in the sinter, but also of the amount of sulfur that is captured by copper and other impurities in the slag.

Rough lead bullion from the blast furnace usually requires preliminary treatment (drossing) in kettles before undergoing refining operations. First, the bullion is cooled to 700 to 800°F (370 - 430°C). Copper and small amounts of sulfur, arsenic, antimony and nickel are removed from solution, collecting on the surface as a dross. This dross, in turn, is treated in a reverberatory furnace where the copper and other metal impurities are further concentrated before being routed to copper smelters for their eventual recovery. Drossed lead bullion is treated for further copper removal by the addition of sulfurbearing material and zinc, and/or aluminum, to lower the copper content to approximately 0.01 percent.

7.6.1.3 Refining - The third and final phase of smelting, the refining of the bullion in cast iron kettles, occurs in five steps:

- Removal of antimony, tin and arsenic.

- Removal of precious metals by Parke's Process, in which zinc combines with gold and silver to form an insoluble intermetallic at operating temperatures.

- Vacuum removal of zinc.

- Removal of bismuth using the Betterson Process, which is the addition of calcium and magnesium to form an insoluble compound with the bismuth that is skimmed from the kettle.

- Removal of remaining traces of metal impurities by addition of NaOH and $NaNO_3$.

The final refined lead, commonly of 99.990 to 99.999 percent purity, is then cast into 100 pound pigs for shipment.

7.6.2 Emissions and Controls[1,2]

Each of the three major lead smelting process steps generates substantial quantities of particulates and/or sulfur dioxide.

Nearly 85 percent of the sulfur present in the lead ore concentrate is eliminated in the sintering operation. In handling process offgases, either a single weak stream is taken from the machine hood at less than 2 percent SO_2, or two streams are taken, one strong stream (5 - 7 percent SO_2) from the feed end of the machine and one weak stream (<0.5 percent SO_2) from the discharge end. Single stream operation has been

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used when there is little or no market for recovered sulfur, so that the uncontrolled weak SO_2 stream is emitted to the atmosphere. When sulfur removal is required, however, dual stream operation is preferred. The strong stream is sent to a sulfuric acid plant, and the weak stream is vented to the atmosphere after removal of particulates.

Table 7.6-1. EMISSION FACTORS FOR PRIMARY LEAD SMELTING PROCESSES WITHOUT CONTROLS[a]

EMISSION FACTOR RATING: B

	Particulates		Sulfur dioxide	
Process	lb/ton	kg/MT	lb/ton	kg/MT
Ore crushing[b]	2.0	1.0	-	-
Sintering (updraft)[c]	213.0	106.5	550.0	275.0
Blast furnace[d]	361.0	180.5	45.0	22.5
Dross reverberatory furnace[b]	20.0	10.0	Neg	Neg
Materials handling[b]	5.0	2.5	-	-

[a] Ore crushing emission factors expressed as lb/ton (kg/MT) of crushed ore. All other emission factors expressed as lb/ton (kg/MT) of lead product.
[b] Reference 2.
[c] References 1, 4, 5 and 6.
[d] References 1, 2 and 7.

When dual gas stream operation is used with updraft sinter machines, the weak gas stream can be recirculated through the bed to mix with the strong gas steam, resulting in a single stream with an SO_2 concentration of about 6 percent. This technique has the overall effect of decreasing machine production capacity, but it does permit a more convenient and economical recovery of the SO_2 by sulfuric acid plants and other control methods.

Without weak gas recirculation, the latter portion of the sinter machine acts as a cooling zone for the sinter and, consequently, assists in the reduction of dust formation during product discharge and screening. However, when recirculation is used, the sinter is usually discharged in a relatively hot state, 745 to 950°F (400 - 500°C), with an attendant increase in particulates. Methods for reducing these dust quantities include recirculation of offgases through the sinter bed, relying upon the filtering effect of the bed, or the ducting of gases from the discharge through a particulate collection device and then to the atmosphere. Because reaction activity has ceased in the discharge area, these latter gases contain little SO_2.

The particulate emissions from sinter machines range from 5 to 20 percent of the concentrated ore feed. When expressed in terms of product weight, a typical emission is estimated to be 213 lb/ton (106.5 kg/MT) of lead produced. This value, along with other particulate and SO_2 factors, appears in Table 7.6-1.

Table 7.6-2. PARTICLE SIZE DISTRIBUTION OF FLUE DUST FROM UPDRAFT SINTERING MACHINES

Size (μm)	Percent by weight
20 - 40	15 - 45
10 - 20	9 - 30
5 - 10	4 - 19
<5	1 - 10

Typical material balances from domestic lead smelters indicate that about 15 percent of the sulfur in the ore concentrate fed to the sinter machine is eliminated in the blast furnace. However, only half of this amount (about 7 percent of the total sulfur in the ore) is emitted as SO_2. The remainder is captured by the slag. The concentration of this SO_2 stream can vary from 500 to 2500 ppm, by volume (1.4 - 7.2 g/m^3), depending on the amount of dilution air injected to oxidize the carbon monoxide and to cool the stream before baghouse particulate removal.

Particulate emissions from blast furnaces contain many different kinds of material, including a range of lead oxides, quartz, limestone, iron pyrites, iron-lime-silicate slag, arsenic, and other metal-containing compounds associated with lead ores. These particles readily agglomerate and are primarily submicron in size, difficult to wet, and cohesive. They will bridge and arch in hoppers. On the average, this dust loading is quite substantial (see Table 7.6-1).

Virtually no sulfur dioxide emissions are associated with the various refining operations. However, a small amount of particulate is generated by the dross reverberatory furnace, about 20 lb/ton (10 kg/MT) of lead.

Finally, minor quantities of particulates are generated by ore crushing and materials handling operations. These emission factors are also presented in Table 7.6-1.

Table 7.6-2 is a listing of size distributions of flue dust from updraft sintering machine effluent. Though these are not fugitive emissions, the size distributions may closely resemble those of the fugitive emissions. Particulate fugitive emissions from the blast furnace consist basically of lead oxides, 92 percent of which are less than 4 μm in size. Uncontrolled emissions from a lead dross reverberatory furnace are mostly less than 1 μm, and this may also be the case with the fugitive emissions.

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Table 7.6-3. EFFICIENCIES OF REPRESENTATIVE CONTROL DEVICES USED WITH PRIMARY LEAD SMELTING OPERATIONS

Control method	Efficiency range, %	
	Particulates	Sulfur dioxide
Centrifugal collector[a]	80 to 90	-
Electrostatic precipitator[a]	95 to 99	-
Fabric filter[a]	95 to 99	-
Tubular cooler (associated with waste heat boiler)[a]	70 to 80	-
Sulfuric acid plant (single contact)[b,c]	99.5 to 99.9	96 to 97
Sulfuric acid plant (dual contact)[b,c]	99.5 to 99.9	96 to 99.9
Elemental sulfur recovery plant[b,d]	-	90
Dimethylaniline (DMA) absorption process[b,e]	-	95 to 99
Ammonia absorption process[b,f]	-	92 to 95

[a] Reference 2.

[b] Reference 1.

[c] High particulate control efficiency due to action of acid plant gas cleaning system. Based on SO_2 inlet concentrations of 5-7%, typical outlet emission levels are 2000 ppm (5.7 g/m^3) for single contact and 500 ppm (1.4 g/m^3) for dual contact.

[d] Collection efficiency for a two stage uncontrolled Claus type plant. Refer to Section 5.18 for more information.

[e] Based on SO_2 inlet concentrations of 4-6%, typical outlet emission levels range from 500-3000 ppm (1.4-8.6 g/m^3).

[f] Based on SO_2 inlet concentrations of 1.5-2.5%, typical outlet emission level is 1200 ppm (3.4 g/m^3).

Table 7.6-4. POTENTIAL FUGITIVE EMISSION FACTORS FOR PRIMARY LEAD SMELTING PROCESSES WITHOUT CONTROLS[a,b]

EMISSION FACTOR RATING: E

Process	Particulates	
	lb/ton	kg/MT
Ore mixing and pelletizing (crushing)	2.26	1.13
Car charging (conveyor loading and transfer) of sinter	0.50	0.25
Sinter machine leakage[c]	0.68	0.34
Sinter return handling	9.00	4.50
Sinter machine discharge, sinter crushing and screening[c]	1.50	0.75
Sinter transfer to dump area	0.20	0.10
Sinter product dump area	0.01	0.005
Blast furnace (charging, blow condition, tapping)	0.16	0.08
Lead pouring to ladle, transferring, and slag pouring[d]	0.93	0.47
Slag cooling[e]	0.47	0.24
Zinc fuming furnace vents	4.60	2.30
Dross kettle	0.48	0.24
Reverberatory furnace leakage	3.00	1.50
Silver retort building	1.80	0.90
Lead casting	0.87	0.44

[a] All factors are expressed in units per end product lead produced, except sinter operations, which are expressed in units per sinter or sinter handled/transferred/charged.

[b] Reference 8, except where noted.

[c] References 9 and 10. Engineering judgement using steel sinter machine leakage emission factor.

[d] Reference 2.

[e] Reference 2. Engineering judgement, estimated to be half the magnitude of lead pouring and ladling operations.

Emission controls on lead smelter operations are for particulates and sulfur dioxide. The most commonly employed high efficiency particulate control devices are fabric filters and electrostatic precipitators, which often follow centrifugal collectors and tubular coolers (pseudogravity collectors). Three of the 6 lead smelters presently operating in the United States use single absorption sulfuric acid plants for control of sulfur dioxide emissions from sinter machines and, occasionally, from blast furnaces. Single stage plants can attain SO_x levels of 2000 ppm (5.7 g/m^3), and dual stage plants can attain levels of 550 ppm (1.6 g/m^3). Typical efficiencies of dual stage sulfuric acid plants in removing sulfur oxides can exceed 99 percent. Other technically feasible SO_2 control methods are elemental sulfur recovery plants and dimethylaniline (DMA) and ammonia absorption processes. These methods and their representative control efficiencies are listed in Table 7.6-3.

References for Section 7.6

1. Charles Darvin and Fredrick Porter, Background Information for New Source Peformance Standards: Primary Copper, Zinc, and Lead Smelters, Volume I, EPA-450/2-74-002a, U.S. Environmental Protection Agency, Research Triangle Park, NC, October 1974.

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5. T. J. Jacobs, "Visit to Amax Lead Company, Boss, MO", Memorandum to Emission Standards and Engineering Division, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, October 28, 1971.

6. Written Communication from R. B. Paul, American Smelting and Refining Co., Glover, MO, to Regional Administrator, U.S. Environmental Protection Agency, Kansas City, MO, April 3, 1973.

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7. Emission Test No. 72-MM-14, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, May 1972.

8. Silver Valley/Bunker Hill Smelter Environmental Investigation (Interim Report), EPA Contract No. 68-02-1343, PEDCo Environmental, Inc., Cincinnati, OH, February 1975.

9. R. E. Iversen, "Meeting with U.S. Environmental Protection Agency and AISI on Steel Facility Emission Factors", Memorandum, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, June 7, 1976.

10. G. E. Spreight, "Best Practicable Means in the Iron and Steel Industry", The Chemical Engineer, London, 271:132-139, March 1973.

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7.18 LEADBEARING ORE CRUSHING AND GRINDING

by Jake Summers, EPA, and Pacific Environmental Services

7.18.1 Process Description

Lead and zinc ores are normally deep mined, whereas copper ores are open pit mined. Lead, zinc and copper are usually found together (in varying percentages) in combination with sulfur and/or oxygen.

In underground mines, the ore is disintegrated by percussive drilling machines, run through a primary crusher, and then conveyed to the surface. In open pit mines, ore and gangue are loosened and pulverized by explosives, scooped up by mechanical equipment, and transported to the concentrator.

Standard crushers, screens, and rod and ball mills classify and reduce the ore to powders in the 65 to 325 mesh range. The finely divided particles are separated from the gangue and are concentrated in a liquid medium by gravity and/or selective flotation, then cleaned, thickened and filtered. The concentrate is dried prior to shipment to the smelter.

7.18.2 Emissions and Controls

Lead emissions are basically fugitive, caused by drilling, blasting, loading, conveying, screening, unloading, crushing and grinding. The primary means of control are good mining techniques and equipment maintenance. These practices include enclosing the truck loading operation, wetting or covering truck loads and stored concentrates, paving the road from mine to concentrator, sprinkling the unloading area, and preventing leaks in the crushing and griding enclosures. Cyclones and fabric filters can be used in the milling operations.

Particulate and lead emission factors for lead ore crushing and materials handling operations are given in Table 7.18-1. Lead emissions from the mining and milling of copper ores are negligible.

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Table 7.18-1. EMISSION FACTORS FOR ORE CRUSHING AND GRINDING

EMISSION FACTOR RATING: B

Type of ore	Particulate emission factor[a]		Lead emission factor[b]	
	lb/ton processed	kg/10^3 kg processed	lb/ton processed	kg/10^3 kg processed
Pb[c]	6.0	3.0	0.3	0.15
Zn	6.0	3.0	0.012	0.006
Cu	6.4	3.2	0.012	0.006
Pb-Zn	6.0	3.0	0.12	0.06
Cu-Pb	6.4	3.2	0.12	0.06
Cu-Zn	6.4	3.2	0.012	0.006
Cu-Pb-Zn	6.4	3.2	0.12	0.06

[a] Reference 1, pp. 4-39

[b] References 1-5

[c] Refer to Section 7.6

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2. W. E. Davis, *Emissions Study of Industrial Sources of Lead Air Pollutants, 1970*, EPA Contract No. 68-02-0271, W. E. Davis and Associates, Leawood, KS, April 1973.

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8.9 COAL CLEANING

8.9.1 Process Description[1,2]

Coal cleaning is a process by which impurities such as sulfur, ash and rock are removed from coal to upgrade its value. Coal cleaning processes are categorized as either physical cleaning or chemical cleaning. Physical coal cleaning processes, the mechanical separation of coal from its contaminants using differences in density, are by far the major processes in use today. Chemical coal cleaning processes are not commercially practical and are therefore not included in this discussion.

The scheme used in physical coal cleaning processes varies among coal cleaning plants but can generally be divided into four basic phases: initial preparation, fine coal processing, coarse coal processing, and final preparation. A sample process flow diagram for a physical coal cleaning plant is presented in Figure 8.9-1.

In the initial preparation phase of coal cleaning, the raw coal is unloaded, stored, conveyed, crushed, and classified by screening into coarse and fine coal fractions. The size fractions are then conveyed to their respective cleaning processes.

Fine coal processing and coarse coal processing use very similar operations and equipment to separate the contaminants. The primary differences are the severity of operating parameters. The majority of coal cleaning processes use upward currents or pulses of a fluid such as water to fluidize a bed of crushed coal and impurities. The lighter coal particles rise and are removed from the top of the bed. The heavier impurities are removed from the bottom. Coal cleaned in the wet processes then must be dried in the final preparation processes.

Final preparation processes are used to remove moisture from coal, thereby reducing freezing problems and weight, and raising the heating value. The first processing step is dewatering, in which a major portion of the water is removed by the use of screens, thickeners and cyclones. The second step is normally thermal drying, achieved by any one of three dryer types: fluidized bed, flash and multilouvered. In the fluidized bed dryer, the coal is suspended and dried above a perforated plate by rising hot gases. In the flash dryer, coal is fed into a stream of hot gases, for instantaneous drying. The dried coal and wet gases are drawn up a drying column and into a cyclone for separation. In the multilouvered dryer, hot gases are passed through a falling curtain of coal. The coal is raised by flights of a specially designed conveyor.

8.9.2 Emissions and Controls[1,2]

Emissions from the initial coal preparation phase of either wet or dry processes consist primarily of fugitive particulates, as coal dust, from roadways, stock piles, refuse areas, loaded railroad cars, conveyor

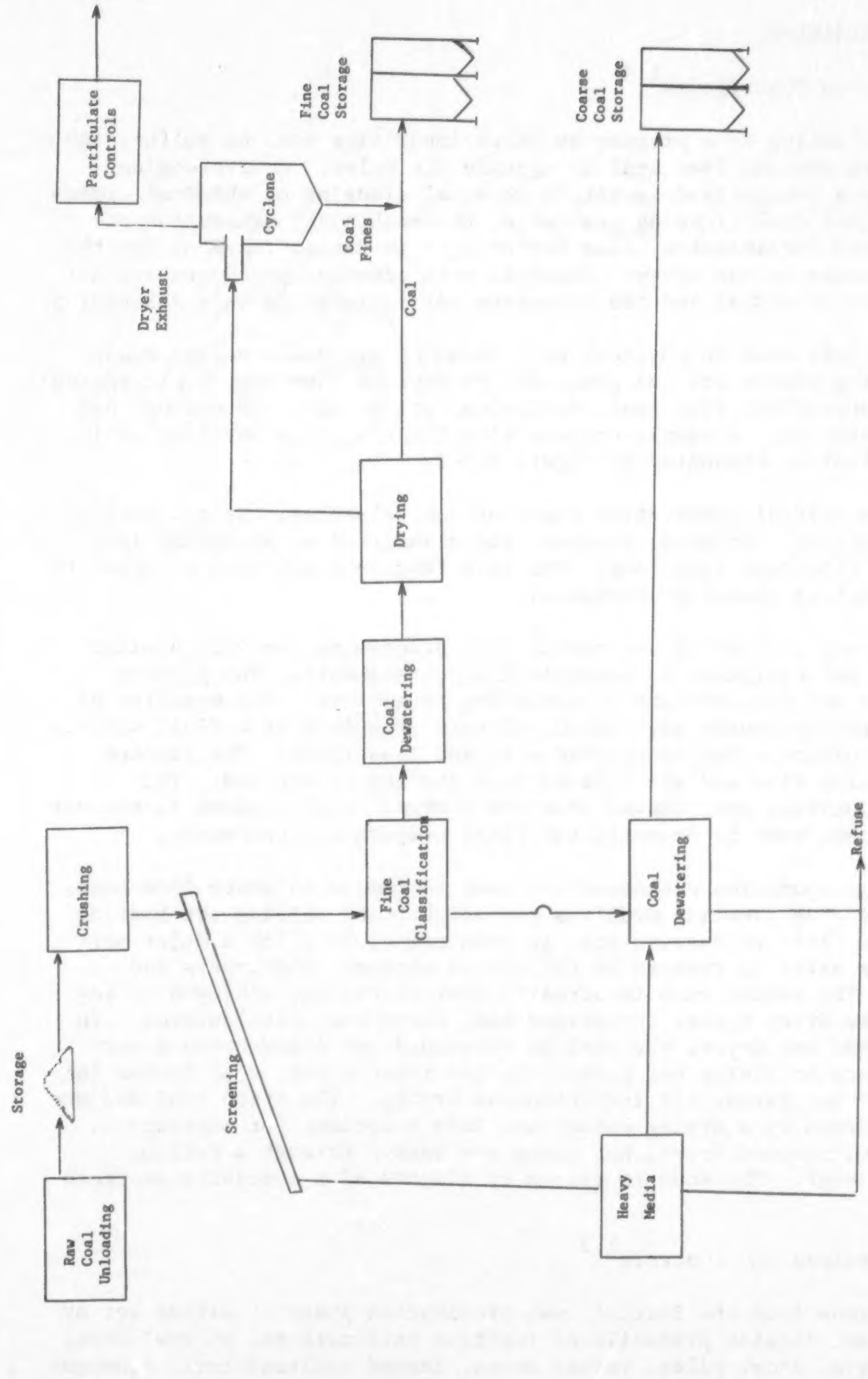
Raw Coal Unloading
Storage
Crushing
Screening
Heavy Media
Refuse
Fine Coal Classification
Coal Dewatering
Coal Dewatering
Drying
Dryer Exhaust
Cyclone
Particulate Controls
Coal Fines
Coal
Fine Coal Storage
Coarse Coal Storage

Figure 8.9-1. Typical coal cleaning plant process flow diagram.

belt pouroffs, crushers, and classifiers. The major control technique used to reduce these emissions is water wetting. Another technique applicable to unloading, conveying, crushing, and screening operations involves enclosing the process area and circulating air from the area through fabric filters.

Table 8.9-1. EMISSION FACTORS FOR COAL CLEANING[a]

EMISSION FACTOR RATING: B

Operation / Pollutant	Fluidized Bed		Flash		Multilouvered	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Particulates						
Before Cyclone	20[b]	10[b]	16[b]	8[b]	25[c]	13[c]
After Cyclone[d]	12[e]	6[e]	10[f]	5[f]	8[c]	4[c]
After Scrubber	0.09[e]	0.05[e]	0.4[f]	0.2[f]	0.1[f]	0.05[c]
SO_2[g]						
After Cyclone	0.43[h]	0.22[h]	–[i]	–	–	–
After Scrubber	0.25	0.13	–	–	–	–
NO_x[j]						
After Scrubber	0.14	0.07	–	–	–	–
VOC[k]						
After Scrubber	0.10	0.05	–	–	–	–

[a] Emission factors expressed as units per weight of coal dried.

[b] References 3 and 4.

[c] Reference 5

[d] Cyclones are standard pieces of process equipment for product collection.

[e] References 6, 7, 8, 9 and 10.

[f] Reference 1.

[g] References 7 and 8. The control efficiency of venturi scrubbers on SO_2 emissions depends on the inlet SO_2 loading, ranging from 70 to 80% removal for low sulfur coals (.7% S) down to 40 to 50% removal for high sulfur coals (3% S).

[h] References 7, 8 and 9.

[i] Not available.

[j] Reference 8. The control efficiency of venturi scrubbers on NO_x emissions is approximately 10 to 25%.

[k] Volatile organic compounds as lbs of carbon/ton of coal dried.

The major emission source in the fine or coarse coal processing phases is the air exhaust from the air separation processes. For the dry cleaning process, this is where the coal is stratified by pulses of air. Particulate emissions from this source are normally controlled with cyclones followed by fabric filters. Potential emissions from wet cleaning processes are very low.

The major source of emissions from the final preparation phase is the thermal dryer exhaust. This emission stream contains coal particles entrained in the drying gases, in addition to the standard products of coal combustion resulting from burning coal to generate the hot gases. Factors for these emissions are presented in Table 8.9-1. The most common technologies used to control this source are venturi scrubbers and mist eliminators downstream from the product recovery cyclones. The particulate control efficiency of these technologies ranges from 98 to 99.9 percent. The venturi scrubbbers also have an NO_x removal efficiency of 10 to 25 percent, and an SO_2 removal efficiency ranging from 70 to 80 percent for low sulfur coals to 40 to 50 percent for high sulfur coals.

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1. Background Information for Establishment of National Standards of Performance for New Sources: Coal Cleaning Industry, Environmental Engineering, Inc., Gainesville, FL, EPA Contract No. CPA-70-142, July 1971.

2. Air Pollutant Emissions Factors, National Air Pollution Control Administration, Contract No. CPA-22-69-119, Resources Research Inc., Reston, VA, April 1970.

3. Stack Test Results on Thermal Coal Dryers (Unpublished), Bureau of Air Pollution Control, Pennsylvania Department of Health, Harrisburg, PA.

4. "Amherst's Answer to Air Pollution Laws", Coal Mining and Processing, 7(2):26-29, February 1970.

5. D. W. Jones, "Dust Collection at Moss No. 3", Mining Congress Journal, 55(7):53-56, July 1969.

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8. Coal Preparation Plant Emission Tests, Consolidation Coal Company, Bishop, West Virginia, EPA Contract No. 68-02-0233, Scott Research Laboratories, Inc., Plumsteadville, PA, November 1972.

9. Coal Preparation Plant Emission Tests, Westmoreland Coal Company, Wentz Plant, EPA Contract No. 68-02-0233, Scott Research Laboratories, Inc., Plumsteadville, PA, April 1972.

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8.11 GLASS FIBER MANUFACTURING

8.11.1 General

Glass fiber manufacturing is the high temperature conversion of various raw materials (predominantly borosilicates) into a homogeneous melt, followed by the fabrication of this melt into glass fibers. The two basic types of glass fiber products, textile and wool, are manufactured by similar processes. Typical flow diagrams are shown in Figure 8.11-1. Glass fiber production can be segmented into three phases: raw materials handling, glass melting and refining, and fiber forming and finishing, this last phase being slightly different in the textile and the wool glass fiber product types.

8.11.1.1 Raw Materials Handling - The primary component of glass fiber is sand, but it also includes varying quantities of feldspar, sodium sulfate, anhydrous borax, boric acid, and many other materials. The bulk supplies are received by rail car and truck, and the lesser volume supplies are received in drums and packages. These raw materials are unloaded by a variety of methods, including drag shovels, vacuum systems and vibrator/gravity systems. Conveying to and from storage piles and silos is accomplished by belts, screws and bucket elevators. From storage, the materials are measured by weight according to the desired product recipe, and then blended well prior to their introduction into the melting unit. The weighing, mixing and charging operations may be conducted in either batch or continuous mode.

8.11.1.2 Glass Melting and Refining - In the glass melting furnace, the raw materials are heated to temperatures ranging from 2700 to 3100°F (1500 - 1700°C) and are transformed through a sequence of chemical reactions to molten glass. Although there are many furnace designs, furnaces are generally large, shallow and well insulated vessels which are heated from above. In operation, raw materials are introduced continuously on top of a bed of molten glass, where they slowly mix and dissolve. Mixing is effected by natural convection, gases rising from chemical reactions, and in some operations, by air injection into the bottom of the bed.

Glass melting furnaces can be categorized, by their fuel source and method of heat application, into four types: recuperative, regenerative, electric, and unit melter. The recuperative, regenerative, and unit melter furnaces can be fueled by either gas or oil. The current trend is shifting from gas fired to oil fired. Recuperative furnaces use a steel heat exchanger, recovering heat from the exhaust gases by exchange with the combustion air. Regenerative furnaces use a lattice of brickwork to recover waste heat from exhaust gases. In the initial mode of operation, hot exhaust gases are routed through a chamber containing a brickwork lattice, while combustion air is heated by passing through

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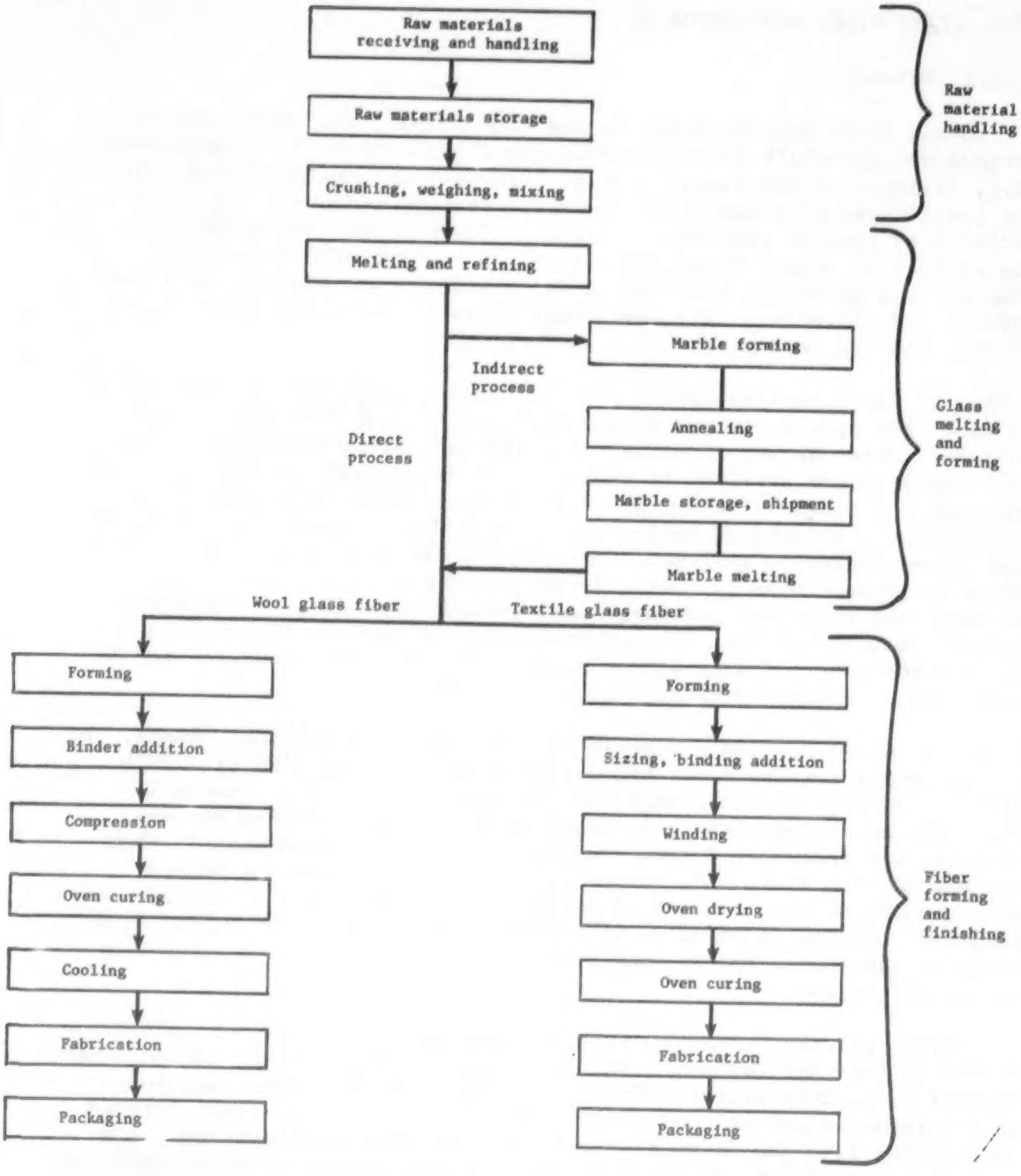
Raw materials receiving and handling
Raw materials storage
Crushing, weighing, mixing
Melting and refining
Marble forming
Indirect process
Annealing
Direct process
Marble storage, shipment
Marble melting
Wool glass fiber
Textile glass fiber
Forming
Binder addition
Compression
Oven curing
Cooling
Fabrication
Packaging
Forming
Sizing, binding addition
Winding
Oven drying
Oven curing
Fabrication
Packaging
Raw material handling
Glass melting and forming
Fiber forming and finishing

Figure 8.11-1. Typical flow diagram of the glass fiber production process.

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another corresponding brickwork lattice. About every twenty minutes, the air flow is reversed, so that the combustion air is always being passed through hot brickwork previously heated by exhaust gases. Electric furnaces melt glass by the passage of an electric current through the melt. Electric furnaces are subcategorized as either hot top or cold top. The hot top electric furnaces use gas for auxiliary heating, and the cold top furnaces use only the electric current. Electric furnaces are currently used only for wool glass fiber production, because of the electrical properties of the glass formulation. Unit melters are used only for the "indirect" marble melting process. Raw materials are fed to unit melters by a continuous screw at the back of the furnace adjacent to the exhaust air discharge. There are no provisions for heat recovery with the unit melter.

In the "indirect" melting process, molten glass passes to a forehearth, where it is drawn off, sheared into globs, and formed into marbles by roll forming. The marbles are then stress relieved in annealing ovens, cooled, and conveyed to storage or transported to other plants for later use. In the "direct" glass fiber process, molten glass passes from the furnace into a refining unit, where bubbles and particles are removed by settling, and the melt is allowed to cool to the proper viscosity for the forming operation.

8.11.1.3 Wool Glass Fiber Forming and Finishing - The two processes used to form wool glass fibers are rotary spinning and flame attenuation/marble melting. In a rotary spinning process, molten glass from the furnace is continuously forced through small holes in the outer edge of a rotating cylinder or spinner. The emerging fibers are entrained in a high velocity air stream and, as they cool, are sprayed with a water soluble phenolic binder. The flame attenuation process, used in conjunction with the marble melting process, involves forcing molten glass through numerous very small orifices in the bottom of the marble remelting furnace. The emerging glass fibers are entrained in a very hot gas stream, which serves to break up and to attenuate the glass fibers into a fine discontinuous fiber mass. The fibers are then sprayed with a highly diluted phenol-formaldehyde water solution which, when cured, becomes a binder. In both fiber forming processes, the binder coated glass fibers are collected on a conveyor belt, compressed by a set of rollers, and conveyed to a binder curing oven. After curing, the continuous fiber batt is cooled in circulating air, attached to an appropriate backing, and prepared for shipping.

8.11.1.4 Textile Glass Fiber Forming and Finishing - Molten glass from either the direct melting furnace or the indirect marble melting furnace is temperature regulated to a precise viscosity and delivered to forming stations. At the forming stations, the molten glass is forced through heated platinum bushings containing numerous very small orifices. The continuous fibers emerging from the orifices are drawn over a roller applicator which applies a coating of water soluble sizing and/or

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coupling agent. The coated fibers are gathered and wound onto a spindle. The spindles of glass fibers are next conveyed to a drying oven, where moisture is removed from the sizing and coupling agents. The spindles are then sent to an oven to cure the coatings. The final fabrication includes twisting, chopping, weaving and packaging of the fiber.

8.11.2 Emissions and Controls

Emissions and controls for glass fiber manufacturing can be categorized by the three production phases with which they are associated. Emission factors for the glass fiber manufacturing industry are summarized in Table 8.11-1.

8.11.2.1 Raw Materials Handling - The major emissions from the raw materials handling phase are fugitive dust and raw material particles generated at each of the material transfer points. Such a point would be where sand pours off a conveyor belt and into a storage silo. The two major control techniques are wet or very moist handling and fabric filters. When fabric filters are used, the transfer points are enclosed, and air from the transfer area is continuously circulated through the fabric filters.

8.11.2.2 Glass Melting and Refining - The emissions from glass melting and refining include volatile organic compounds evolving from the melt, raw material particulates entrained in the furnace flue gas, and if furnaces are heated with fossil fuels, combustion products. The variations in emission rates among furnaces are attributable to variations in operating temperature, raw material composition, fuels, and flue gas flow rates. Electric furnaces generally have the lowest emission rates, because of the lack of combustion products and of the lower temperature of the melt surface due to bottom heating. Emission control for furnaces consists primarily of fabric filtration. Fabric filters are effective on particulates and SO_x and, to a lesser extent, on CO, NO_x and fluorides. This effectiveness on these compounds is attributable both to condensation on filterable particulates and to chemical reaction with particulates trapped on the filters. Reported fabric filter efficiencies on regenerative and recuperative wool furnaces are for particulates, 95+ percent; SO_x, 99+ percent; CO, 30 percent; fluoride, 91 to 99 percent. Efficiencies on other furnaces are lower because of lower emission loading and pollutant characteristics.

8.11.2.3 Fiber Forming and Finishing - Emissions from the forming and finishing processes include glass fiber particles, resin particles, hydrocarbons (primarily phenols and aldehydes), and combustion products from dryers and ovens. Emissions are generally lower in the textile fiber glass process, due to the lower turbulence in the forming step, the roller application of coatings, and the use of much less coating per ton of fiber produced. Because of the higher emission rates, control technology is most effective on the wool fiber segment of the industry.

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Table 8.11-1. EMISSION FACTORS FOR GLASS FIBER MANUFACTURING WITHOUT CONTROLS[a]

EMISSION FACTOR RATING: B

	Particulates		SO_x		CO		NO_x		Hydrocarbons[b]		Fluorides	
	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	kg/MT
Unloading and Conveying[c]	3.0	1.5	f	f	f	f	f	f	f	f	f	f
Storage Bins[c]	0.2	0.1	f	f	f	f	f	f	f	f	f	f
Mixing and Weighing[c]	0.6	0.3	f	f	f	f	f	f	f	f	f	f
Crushing and Batch Charging[c]	neg	neg	f	f	f	f	f	f	f	f	f	f
Glass Furnace - wool[d]												
Electric	0.5	0.25	0.04	0.02	0.05	0.025	0.27	0.14	e	e	0.002	0.001
Gas-Regenerative	22	11	10	5	0.25	0.13	5	2.5	e	e	0.12	0.06
Gas-Recuperative	25-30	13-15	10	5	0.25	0.13	1.7	0.85	e	e	0.11	0.06
Gas-Unit Melter	9	4.5	0.6	0.3	0.25	0.13	0.3	0.15	e	e	0.12	0.06
Glass Furnace - textile[d]												
Recuperative	2	1	3	1.5	.5	0.25	20	10	f	f	2	1
Regenerative	16	8	30	15	1	0.5	20	10	f	f	2	1
Unit Melter	6	3	e	e	0.9	0.45	20	10	f	f	2	1
Forming - wool[d]												
Rotary Spun	58	29	f	f	f	f	f	f	7	3.5	e	e
Flame Attenuation	2	1	f	f	f	f	f	f	0.3	0.15	e	e
Forming - textile[e]	1	0.5	f	f	f	f	f	f	neg	neg	f	f
Oven Curing - wool[d]												
Rotary Spun	9	4.5	e	e	1.7	0.85	1.1	0.55	3	1.5	e	e
Flame Attenuation	6	3	e	e	3.5	1.8	2	1	7	3.5	e	e
Rotary Spun[d] Cooling-wool	1.3	0.65	e	e	e	e	0.3	0.15	.04	0.02	f	f
Oven Curing and Cooling-textile	1.2	0.6	f	f	1.5	0.75	2.6	1.3	neg	neg	f	f

[a] Emission factors expressed as units per unit weight of raw material processed.
[b] Includes primarily phenols and aldehydes, and to a lesser degree methane.
[c] Reference 1.
[d] Reference 2.
[e] No data are available.
[f] Not applicable.

Emission controls for the wool fiber forming process include wet scrubbing, electrostatic precipitation, filtration, use of lower temperatures, and use of partially cured binders. Emission controls for curing ovens include incineration, afterburners and high energy filters. Controls applicable to the cooling process include wet scrubbers and high energy filters. The control efficiencies of afterburners on hydrocarbon emissions from wool rotary spinning facilities are reported to be 93 percent on forming equipment and 77 percent on the curing oven. Control efficiency of scrubbers on hydrocarbon emissions from wool rotary spinning cooling operations is 90 percent.

Reference for Section 8.11

1. J. R. Schorr, et al., Source Assessment: Pressed and Blown Glass Manufacturing Plants, EPA-600/2-77-005, U. S. Environmental Protection Agency, Research Triangle Park, NC, January 1977.

8.18 PHOSPHATE ROCK PROCESSING

8.18.1 General

The processing of phosphate rock for use in fertilizer manufacture consists of beneficiation, drying or calcining, and grinding stages. Since the primary use of phosphate rock is in the manufacture of phosphatic fertilizer, only those phosphate rock processing operations associated with fertilizer manufacture are discussed here. A flow diagram of these operations is shown in Figure 8.18-1.

Phosphate rock from the mines is first sent to beneficiation units to remove impurities. Steps used in beneficiation depend on the type of rock. A typical beneficiation unit for processing phosphate rock mined in Florida (about 78 percent of United States plant capacity in 1978) begins with wet screening to separate pebble rock (smaller than 1/4 inch and larger than 14 mesh) from the balance of the rock. The pebble rock is sent to the rock dryer, and the fraction smaller than 14 mesh is slurried and treated by two-stage flotation. The flotation process uses hydrophilic or hydrophobic chemical reagents with aeration to separate suspended particles. Phosphate rock mined in North Carolina (about 8 percent of United States capacity in 1978) does not contain pebble rock. In processing this type of phosphate, the fraction larger than 1/4 inch is sent to a hammer mill and then recycled to the screens, and the fraction less than 14 mesh is treated by two-stage floation, like Florida rock. The sequence of beneficiation steps at plants processing Western hard phosphate rock (about 10 percent of United States capacity in 1978) typically includes crushing, classification and filtration. The size reduction is carried out in several steps, the last of which is a slurry grinding process using a wet rod mill to reduce the rock to particles about the size of beach sand. The slurry is then classified by size in hydroclones to separate tailings (clay and particles smaller than about 100 mesh), and the rock is then filtered from the slurry. Beneficiated rock is commonly stored in open wet piles. It is reclaimed from these piles by one of several methods (including skip loaders, underground conveyor belts, and aboveground reclaim trolleys) and is then conveyed to the next processing step.

The wet beneficiated phosphate rock is then dried or calcined, depending on its organic content. Florida rock is relatively free of organics and is dried in direct fired dryers at about 250°F (120°C), where the moisture content of the rock falls from 10-15 percent to 1-3 percent. Both rotary and fluidized bed dryers are used, but rotary dryers are more common. Most dryers are fired with natural gas or fuel oil (No. 2 or No. 6), with many equipped to burn more than one type of fuel. Unlike Florida rock, phosphate rock mined from other reserves contains organics and must be heated to 1400° - 1600°F (760°C - 870°C) to remove them. Fluidized bed calciners are most commonly used for this purpose, but rotary calciners are also used. After drying, the rock is usually conveyed to storage silos on weather protected conveyors and, from there, to grinding mills.

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Table 8.18-1. UNCONTROLLED PARTICULATE EMISSION FACTORS FOR PHOSPHATE ROCK PROCESSING[a]

EMISSION FACTOR RATING: B

Type of Source	Emissions	
	lb/ton	kg/MT
Drying[b]	5.7 (1.4 - 14.0)	2.9 (0.7 - 7.0)
Calcining[b]	15.4 (3.8 - 38.0)	7.7 (1.9 - 19.0)
Grinding[b]	1.5 (0.4 - 4.0)	0.8 (0.2 - 2.0)
Transfer and storage[c]	2	1
Open storage piles[d]	40	20

[a] Emission factors expressed as units per unit weight of processed phosphate rock. Ranges in parentheses.
[b] Reference 1.
[c] Reference 3.
[d] Reference 4.

Dried or calcined rock is ground in roll or ball mills to a fine powder, typically specified as 60 percent by weight passing a 200 mesh sieve. Rock is fed into the mill by a rotary valve, and ground rock is swept from the mill by a circulating air stream. Product size classification is provided by "revolving whizzers" and by an air classifier. Oversize particles are recycled to the mill, and product size particles are separated from the carrying air stream by a cyclone.

8.18.2 Emissions and Controls

The major emission sources for phosphate rock processing are dryers, calciners and grinders. These sources emit particulates in the form of fine rock dust. Emission factors for these sources are presented in Table 8.18-1. Beneficiation has no significant emission potential, since the operations involve slurries of rock and water.

Emissions from dryers depend on several factors, including fuel types, air flow rates, product moisture content, speed of rotation, and the type of rock. The pebble portion of Florida rock receives much less washing than the concentrate rock from the floation processes. It has a higher clay content and generates more emissions when dried. No significant differences have been noted in gas volume or emissions from fluid bed or rotary dryers. A typical dryer processing 250 tons per hour (230 metric tons per hour) of rock will discharge between 70,000 and 100,000 dscfm (31 - 45 dry nm^3/sec) of gas, with a particulate loading of 0.5 to

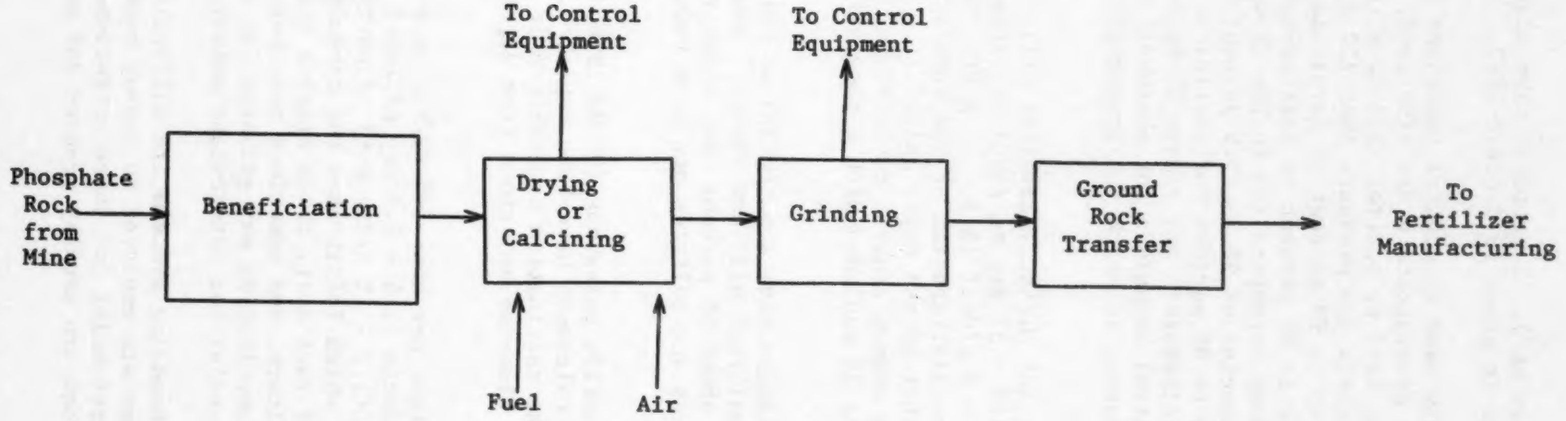
Phosphate Rock from Mine
Beneficiation
To Control Equipment
Drying or Calcining
Fuel
Air
To Control Equipment
Grinding
Ground Rock Transfer
To Fertilizer Manufacturing

Figure 8.18-1. Typical flowsheet for processing phosphate rock.

5 grams/dscf (1.2 - 12 grams/dry nm^3). A particle size distribution of the uncontrolled dust emissions is given in Table 8.18-2.

Scrubbers are most commonly used to control emissions from phosphate rock dryers, but electrostatic precipitators are also used. Fabric filters are not currently being used to control emissions from dryers. Venturi scrubbers with a relatively low pressure loss (12 inches of water, or 3000 Pa) may remove 80 to 99 percent of particulates 1 to 10 micrometers in diameter, and 10 to 80 percent of particulates less than 1 micrometer. High pressure drop scrubbers (30 inches of water, or 7500 Pa) may have collection efficiencies of 96 to 99.9 percent for 1-10 micrometer particulates and 80 to 86 percent for particles less than 1 micrometer. Electrostatic precipitators may remove 90 to 99 percent of all particulates. Another control technique for phosphate rock dryers is use of the wet grinding process, in which the drying step is eliminated.

A typical 50 ton per hour (45 MT/hour) calciner will discharge about 30,000 to 60,000 dscfm (13 - 27 dry nm^3/sec) of exhaust gas, with a particulate loading of 0.5 to 5 g/dscf (1.2 - 12 g/dry nm^3). As shown in Table 8.18-2, the size distribution of the uncontrolled calciner emissions is very similar to that of the dryer emissions. As with dryers, scrubbers are the most common control devices used for calciners. At least one operating calciner is equipped with a precipitator. Fabric filters could also be applied.

Oil fired dryers and calciners have a potential to emit sulfur oxides when high sulfur residual fuel oils are burned. However, phosphate rock typically contains about 55 percent CaO, which reacts with the SO_x to form calcium sulfites and sulfates and thus reduces SO_x emissions.

Low levels of gaseous fluoride emissions (0.002 lb/ton or 0.001 kg/MT) of rock processed from calciners have been reported, although other reports indicate that the calcination temperature is too low to drive off gaseous fluorides. Fluoride emissions from dryers are negligible.

A typical grinder of 50 tons per hour (45 MT/hr) capacity will discharge about 3500 to 5500 dscfm (1.6 - 2.5 dry nm^3/sec) of air containing 0.5 to 5.0 gr/dscf (1.2 - 12 g/dry nm^3) of particulates. The air discharged is "tramp air" which infiltrates the circulating streams. To avoid fugitive emissions of rock dust, these streams are operated at negative pressure. Fabric filters, and sometimes scrubbers, are used to control grinder emissions. Substituting wet grinding for conventional grinding would reduce the potential for particulate emissions.

Emissions from material handling systems are difficult to quantify, since several different systems are employed to convey rock. Moreover, a large part of the emission potential for these operations is fugitives. Conveyor belts moving dried rock are usually covered and sometimes

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enclosed. Transfer points are sometimes hooded and evacuated. Bucket elevators are usually enclosed and evacuated to a control device, and ground rock is generally conveyed in totally enclosed systems with well defined and easily controlled discharge points. Dry rock is normally stored in enclosed bins or silos which are vented to the atmosphere, with fabric filters frequently used to control emissions.

Table 8.18-2. PARTICLE SIZE DISTRIBUTION OF EMISSIONS FROM PHOSPHATE ROCK DRYERS AND CALCINERS[a]

Diameter (μm)	Percent Less Than Size	
	Dryers	Calciners
10.0	82	96
5.0	60	81
2.0	27	52
1.0	11	26
0.8	7	10
0.5	3	5

[a] Reference 1.

References for Section 8.18

1. Background Information: Proposed Standards for Phosphate Rock Plants (Draft), EPA-450/3-79-017, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1979.

2. "Sources of Air Pollution and Their Control", Air Pollution, Volume III, 2nd Ed., Arthur Stern, ed., New York, Academic Press, 1968, pp. 221-222.

3. Unpublished data from phosphate rock preparation plants in Florida, Midwest Research Institute, Kansas City, MO, June 1970.

4. Control Techniques for Fluoride Emissions, Internal document, Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, pp. 4-34, 4-36 and 4-46.

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8.21 COAL CONVERSION

In addition to its direct use for combustion, coal can be converted to organic gases and liquids, thus allowing the continued use of conventional oil and gas fired processes when oil and gas supplies are not available. Currently, there is little commercial coal conversion in the United States. Consequently, it is very difficult to determine which of the many conversion processes will be commercialized in the future. The following sections provide general process descriptions and general emission discussions for high-, medium- and low-Btu gasification (gasifaction) processes and for catalytic and solvent extraction liquefaction processes.

8.21.1 Process Description[1-2]

8.21.1.1 Gasification - One means of converting coal to an alternate form of energy is gasification. In this process, coal is combined with oxygen and steam to produce a combustible gas, waste gases, char and ash. The more than 70 coal gasification systems currently available or being developed (1979) can be classified by the heating value of the gas produced and by the type of gasification reactor used. High-Btu gasification systems produce a gas with a heating value greater than 900 Btu/scf (33,000 J/m^3). Medium-Btu gasifiers produce a gas having a heating value between 250 - 500 Btu/scf (9,000 - 19,000 J/m^3). Low-Btu gasifiers produce a gas having a heating value of less than 250 Btu/scf (9,000 J/m^3).

The majority of the gasification systems consist of four operations: coal pretreatment, coal gasification, raw gas cleaning and gas beneficiation. Each of these operations consists of several steps. Figure 8.21-1 is a flow diagram for an example coal gasification facility.

Generally, any coal can be gasified if properly pretreated. High moisture coals may require drying. Some caking coals may require partial oxidation to simplify gasifier operation. Other pretreatment operations include crushing, sizing, and briqueting of fines for feed to fixed bed gasifiers. The coal feed is pulverized for fluid or entrained bed gasifiers.

After pretreatment, the coal enters the gasification reactor, where it reacts with oxygen and steam to produce a combustible gas. Air is used as the oxygen source for making low-Btu gas, and pure oxygen is used for making medium- and high-Btu gas (inert nitrogen in the air dilutes the heating value of the product). Gasification reactors are classified by type of reaction bed (fixed, entrained or fluidized), the operating pressure (pressurized or atmospheric), the method of ash removal (as molten slag or dry ash), and the number of stages in the gasifier (one or two). Within each class, gasifiers have similar emissions.

The raw gas from the gasifier contains varying concentrations of carbon monoxide, carbon dioxide, hydrogen, methane, other organics, hydrogen sulfide, miscellaneous acid gases, nitrogen (if air was used as the oxygen source), particulates and water. Four gas purification processes may be required to prepare the gas for combustion or further beneficiation: particulate removal, tar and oil removal, gas quenching and cooling, and acid gas removal. The primary function of the particulate removal process is the removal of coal dust, ash and tar aerosols in the raw product gas. During tar and oil removal and gas quenching and cooling, tars and oils are condensed, and other impurities such as ammonia are scrubbed from raw product gas using either aqueous or organic scrubbing liquors. Acid gases such as H_2S, COS, CS_2, mercaptans, and CO_2 can be removed from gas by an acid gas removal process. Acid gas removal processes generally absorb the acid gases in a solvent, from which they are subsequently stripped, forming a nearly pure acid gas waste stream with some hydrocarbon carryover. At this point, the raw gas is classified as either a low-Btu or medium-Btu gas.

To produce high-Btu gas, the heating value of the medium-Btu gas is raised by shift conversion and methanation. In the shift conversion process, H_2O and a portion of the CO are catalytically reacted to form CO_2 and H_2. After passing through an absorber for CO_2 removal, the remaining CO and H_2 in the product gas are reacted in a methanation reactor to yield CH_4 and H_2O.

There are also many auxiliary processes accompanying a coal gasification facility, which provide various support functions. Among the typical auxiliary processes are oxygen plant, power and steam plant, sulfur recovery unit, water treatment plant, and cooling towers.

8.21.1.2 Liquefaction - Liquefaction is a conversion process designed to produce synthetic organic liquids from coal. This conversion is achieved by reducing the level of impurities and increasing the hydrogen to carbon ratio of coal to the point that is becomes fluid. Currently, there are over 20 coal liquefaction processes in various stages of development by both industry and Federal agencies (1979). These processes can be grouped into four basic liquefaction techniques:

- Indirect liquefaction
- Pyrolysis
- Solvent extraction
- Catalytic liquefaction

Indirect liquefaction involves the gasification of coal followed by the catalytic conversion of the product gas to a liquid. Pyrolysis liquefaction involves heating coal to very high temperatures, thereby cracking the coal into liquid and gaseous products. Solvent extraction uses a solvent generated within the process to dissolve the coal and to transfer externally produced hydrogen to the coal molecules. Catalytic liquefaction resembles solvent extraction, except that hydrogen is added to the coal with the aid of a catalyst.

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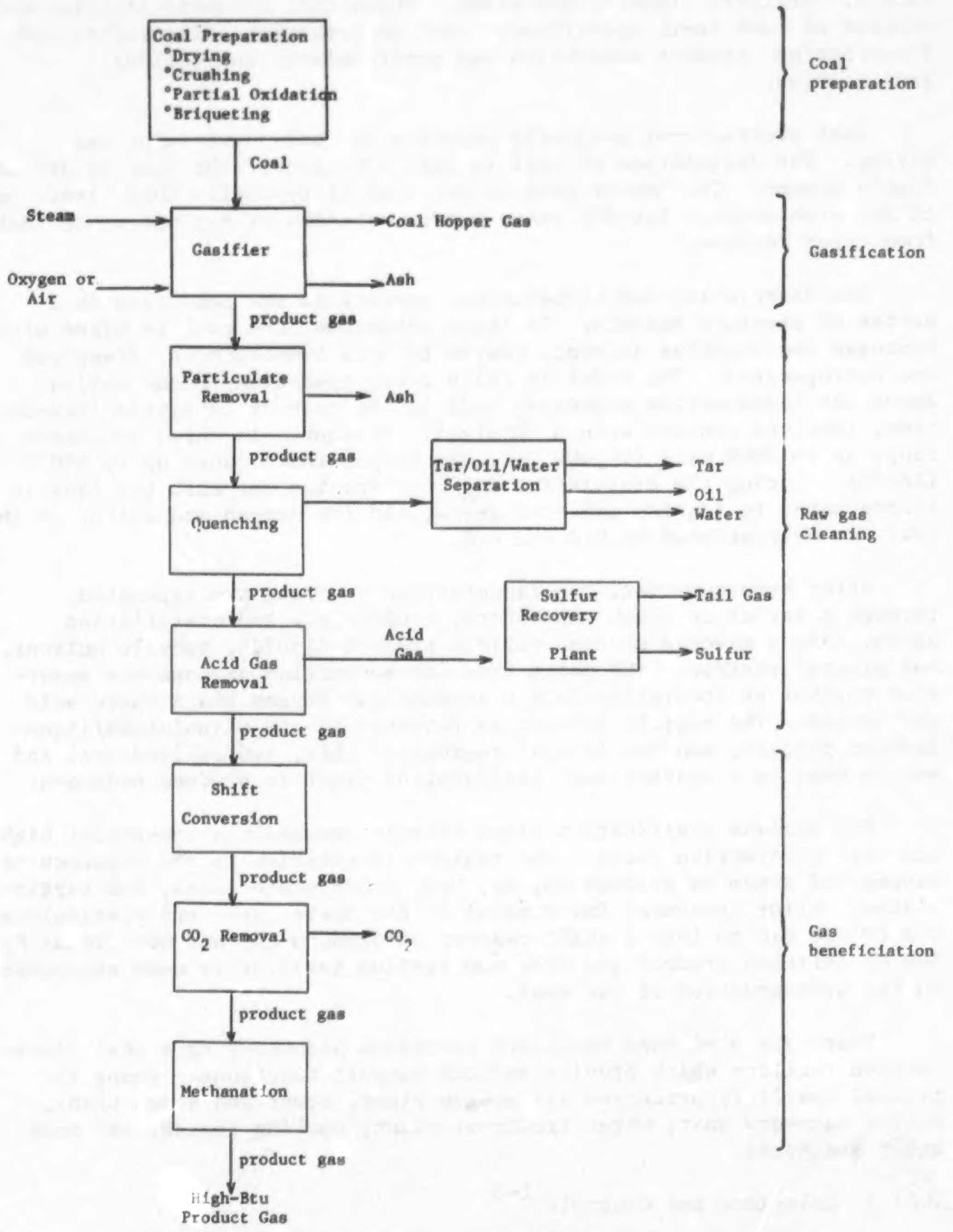
Coal Preparation
°Drying
°Crushing
°Partial Oxidation
°Briqueting
Coal preparation
Coal
Steam
Gasifier
Coal Hopper Gas
Oxygen or Air
Ash
Gasification
product gas
Particulate Removal
Ash
product gas
Tar/Oil/Water Separation
Tar
Oil
Water
Quenching
Raw gas cleaning
product gas
Sulfur Recovery Plant
Tail Gas
Acid Gas
Sulfur
Acid Gas Removal
product gas
Shift Conversion
product gas
CO_2 Removal
CO_2
Gas beneficiation
product gas
Methanation
product gas
High-Btu Product Gas

Figure 8.21-1. Flow diagram of typical coal gasification plant.

Figure 8.21-2 presents the flow diagram of a typical solvent extraction or catalytic liquefaction plant. These coal liquefaction processes consist of four basic operations: coal pretreatment, dissolution and liquefaction, product separation and purification, and residue gasification.

Coal pretreatment generally consists of coal pulverizing and drying. The dissolution of coal is best effected if the coal is dry and finely ground. The heater used to dry coal is typically coal fired, but it may also combust low-BTU value product streams or may use waste heat from other sources.

The dissolution and liquefaction operations are conducted in a series of pressure vessels. In these processes, the coal is mixed with hydrogen and recycled solvent, heated to high temperatures, dissolved and hydrogenated. The order in which these operations occur varies among the liquefaction processes and, in the case of catalytic liquefaction, involves contact with a catalyst. Pressures in these processes range up to 2000 psig (14,000 Pa), and temperatures range up to 900°F (480°C). During the dissolution and liquefaction process, the coal is hydrogenated to liquids and some gases, and the oxygen and sulfur in the coal are hydrogenated to H_2O and H_2S.

After hydrogenation, the liquefaction products are separated, through a series of flash separators, condensers, and distillation units, into a gaseous stream, various product liquids, recycle solvent, and mineral residue. The gases from the separation process are separated further by absorption into a product gas stream and a waste acid gas stream. The recycle solvent is returned to the dissolution/liquefaction process, and the mineral residue of char, undissolved coal and ash is used in a conventional gasification plant to produce hydrogen.

The residue gasification plant closely resembles a convential high-Btu coal gasifaction plant. The residue is gasified in the presence of oxygen and steam to produce CO, H_2, H_2O, other waste gases, and particulates. After treatment for removal of the waste gases and particulates, the CO and H_2O go into a shift reactor to produce CO_2 and additional H_2. The H_2 enriched product gas from the residue gasifier is used subsequently in the hydrogenation of the coal.

There are also many auxiliary processes accompanying a coal liquefaction facility which provide various support functions. Among the typical auxiliary processes are oxygen plant, power and steam plant, sulfur recovery unit, water treatment plant, cooling towers, and sour water strippers.

8.21.2 Emissions and Controls $^{1-3}$

Although characterization data are availabe for some of the many developing coal conversion processes, describing these data in detail would require a more extensive discussion than possible here. So, this

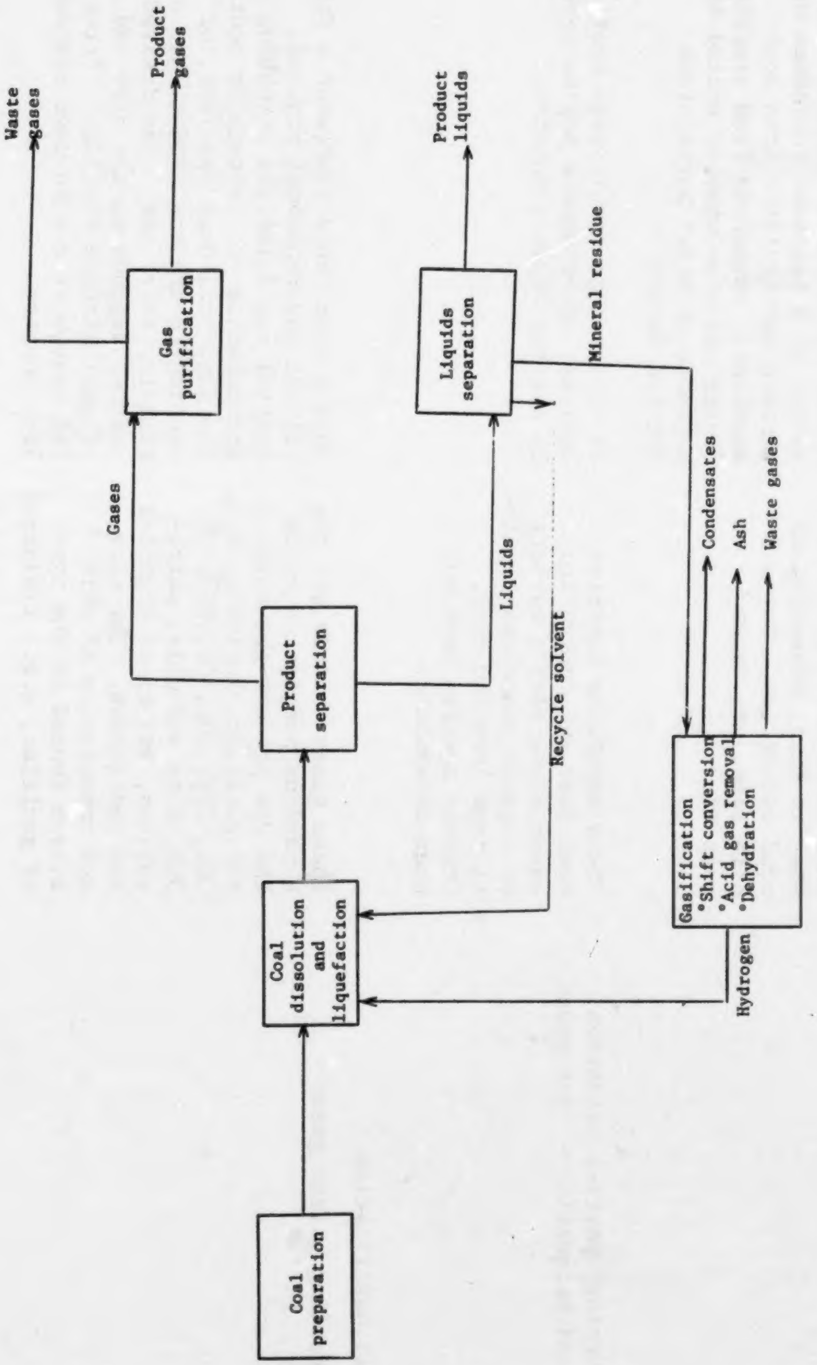
Coal preparation
Coal dissolution and liquefaction
Product separation
Gases
Liquids
Gas purification
Waste gases
Product gases
Liquids separation
Product liquids
Mineral residue
Recycle solvent
Gasification
°Shift conversion
°Acid gas removal
°Dehydration
Hydrogen
Condensates
Ash
Waste gases

Figure 8.21-2. Flow diagram for an example coal liquefaction facility.

Table 8.21-1. SUMMARY OF EMISSIONS FROM COAL GASIFICATION PLANTS[1-3]

Operation/Emission Source/Stream	Characterization of Emission	Summary of Emission Control Choices
Coal Pretreatment		
Storage, handling and crushing/sizing - Dust emissions	Emissions from coal storage, handling and crushing/sizing mainly consist of coal dust. These emissions vary from site to site, depending on wind velocities, coal and pile size, and water content.	Water sprays and polymer coatings are used to control dust emissions from coal storage piles. Water sprays and enclosed equipment are vented to a baghouse to reduce or capture particulates from coal handling. Emissions from crushing/sizing are also usually vented to a baghouse or other particulate control device.
Drying, partial oxidation and briqueting - Vent gases	These emissions comprise coal dust and combustion gases along with a variety of organic compounds devolatilized from the coal. Organic species have not been determined.	In addition to particulate control devices, afterburners may be needed to destroy organic species.
Coal Gasification		
Feeding - Vent gases	These gases contain all the hazardous species found in the raw product gas exiting the gasifier, including H_2S, COS, CS_2, SO_2, CO, NH_3, CH_4, HCN, tars and oils, particulates, and trace organics and inorganics. The size and composition of this stream depend on the type of gasifier, e.g., fluidized	This stream could represent a significant environmental problem. Control could include scrubbing or incineration (to capture or destroy the most hazardous species), or venting to the raw product gas or gasifier inlet air. The desired control depends on the type and size of gasification facility. Screw fed conveyors can be used instead of lock hoppers.

Table 8.21-1 (cont.). SUMMARY OF EMISSIONS FROM COAL GASIFICATION PLANTS[1-3]

Operation/Emission Source/Stream	Characterization of Emission	Summary of Emission Control Choices
	bed gasifiers emit substantially fewer tars and oils than fixed bed gasifiers.	
Ash removal - Vent gases	Emissions from ash removal and disposal depend on the type of gasifier. Ash dust will be released from all gasifiers that are not slagging or agglomerating ash units. If contaminated water is used for ash quenching, volatile organic and inorganic species may be released from the quench liquor.	These emissions have not been sufficiently characterized to recommend necessary controls. Particulate or organic emission controls could be needed. Clean water may be used for quenching to avoid the potential emission of hazardous volatile organic and inorganic species.
Startup - Vent gases	This vent gas initially resembles a coal combustion gas in composition. As the operating temperature of the gas increases, the startup gas begins to resemble the raw product gas.	A flare can incinerate the combustible constituents in the startup gas, but heavy tars and coal particulates will affect the performance of the flare. Potential problems with tars and particulates can be avoided by using charcoal or coke as the startup fuel.
Fugitives	These emissions have not been characterized, but they comprise hazardous species found in the raw product gas such as H_2S, COS, CS_2, CO, HCN, CH_4 and others.	Control methods mainly involve good maintenance and operating practices.

Table 8.21-1 (cont.). SUMMARY OF EMISSIONS FROM COAL GASIFICATION PLANTS[1-3]

Operation/Emission Source/Stream	Characterization of Emission	Summary of Emission Control Choices
Raw Gas Cleaning/Beneficiation		
Fugitives	These emissions have not been characterized, but they comprise hazardous species found in the various gas streams. Other emissions result from leaks from pump seals, valves, flanges and by-product storage tanks.	Control methods mainly involve good maintenance and operating practices.
Acid Gas Removal - Tail gases	The composition of this stream highly depends on the kind of acid gas removal employed. Processes featuring the direct removal and conversion of sulfur species in a single step (e.g., the Stretford process) produce tail gases containing small amounts of NH_3 and other species. Processes absorbing and subsequently desorbing a concentrated acid gas stream require a sulfur recovery process to avoid the emission of highly toxic gases having quantities of H_2S.	Some tail gas streams (from the Stretford process, for example) are probably not very hazardous. These streams have not been characterized, nor have control technology needs been demonstrated. Tail gases from other processes always require the removal of sulfur species. Trace constituents such as organics, trace elements and cyanides affect the performance of the auxiliary sulfur removal processes.
Auxiliary Operations		
Sulfur recovery	See Section 5.18	
Power and steam generation	See Section 1.1	

Table 8.21-1 (cont.). SUMMARY OF EMISSIONS FROM COAL GASIFICATION PLANTS[1-3]

Operation/Emission Source/Stream	Characterization of Emission	Summary of Emission Control Choices
Wastewater Treatment - Expansion gases	These streams comprise volatile organic and inorganic species that desorb from quenching/cooling liquor. The streams potentially include all the hazardous species found in the product gas.	These streams could pose significant environmental problems. Potential controls are generally similar to those needed to treat coal feeding vent gases.
Cooling Towers - Exhaust gas	Emissions from cooling towers are usually minor. However, if contaminated water is used as cooling water makeup, volatile organic and inorganic species from the contaminated water could be released.	The potential emission of hazardous volatile organic and inorganic species may be avoided by using clean water for cooling.

Section will cover emissions and controls for coal conversion processes on a qualitative level only.

8.21.2.1 Gasification - All of the major operations associated with low-, medium- and high-Btu gasification technology (coal pretreatment, gasification, raw gas cleaning, and gas beneficiation) can produce potentially hazardous air emissions. Auxiliary operations, such as sulfur recovery and combustion of fuel for electricity and steam generation, could account for a major portion of the emissions from a gasification plant. Discharges to the air from both major and auxiliary operations are summarized and discussed in Table 8.21-1.

Dust emissions from coal storage, handling and crushing/sizing can be controlled with available techniques. Controlling air emissions from coal drying, briqueting and partial oxidation processes is more difficult because of the volatile organics and possible trace metals liberated as the coal is heated.

The coal gasification process itself appears to be the most serious potential source of air emissions. The feeding of coal and the withdrawal of ash release emissions of coal or ash dust and organic and inorganic gases that are potentially toxic and carcinogenic. Because of their reduced production of tars and condensable organics, slagging gasifiers pose less severe emission problems at the coal inlet and ash outlet.

Gasifiers and associated equipment also will be sources of potentially hazardous fugitive leaks. These leaks may be more severe from pressurized gasifiers and/or gasifiers operating at high temperatures.

Raw gas cleaning and gas beneficiation operations appear to be smaller sources of potential air emissions. Fugitive emissions have not been characterized but are potentially large. Emissions from the acid gas removal process depend on the kind of removal process employed at a plant. Processes used for acid gas removal may remove both sulfur compounds and carbon dioxide or may be operated selectively to remove only the sulfur compounds. Typically, the acid gases are stripped from the solvent and processed in a sulfur plant. Some processes, however, directly convert the absorbed hydrogen sulfide to elemental sulfur. Emissions from these direct conversion processes (e.g., the Stretford process) have not been characterized but are probably minor, consisting of CO_2, air, moisture and small amounts of NH_3.

Emission controls for two auxiliary processes (power and steam generation and sulfur recovery) are discussed elsewhere in this document (Sections 1.1 and 5.18, respectively). Gases stripped or desorbed from process wastewaters are potentially hazardous, since they contain many of the components found in the product gas. These include sulfur and nitrogen species, organics, and other species that are toxic and potentially carcinogenic. Possible controls for these gases include incineration, byproduct recovery, or venting to the raw product gas or inlet

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Table 8.21-2. SUMMARY OF EMISSIONS FROM COAL LIQUEFACTION FACILITY[1]

Operation/Emission Source/Stream	Characterization of Emission	Summary of Emission Control Choices
Coal Preparation		
Storage, handling and crushing/sizing	Emissions primarily consist of fugitive coal dust generated at transfer points and points exposed to wind erosion. A potentially significant source.	Water sprays and polymer coatings are used to control dust from storage sites. Water sprays and enclosures vented to baghouses are effective on crushing and sizing operations.
Drying	Emissions include coal dust, combustion products from heater, and organics volatilized from the coal. A potentially significant particulate source.	Scrubbers, electrostatic precipitators, and baghouses are effective coal dust controls. Low drying temperatures reduce organics formation.
Coal Dissolution and Liquefaction		
Process heater (fired with low grade fuel gas)	Emissions consist of combustion products (particulates, CO, SO_2, NO_x and HC).	Fuel desulfurization for SO_2 control and combustion modifications for reduced CO, HC and NO_x.
Slurry mix tank	Evolution of dissolved gases from recycle solvent (HC, acid gases, organics) due to low pressure (atmospheric) of tank. Some pollutants are toxic even in small quantities.	Controls might include scrubbing, incineration or venting to heater combustion air supply.
Product Separation and Liquefaction - Sulfur recovery plant	Tail gases containing acids (H_2S, SO_2, COS, CS_2 NH_3 and particulate sulfur).	Venting to tail gas treatment plant, or operating sulfur recovery plant at higher efficiency.

Table 8.21-2 (cont.). SUMMARY OF EMISSIONS FROM COAL LIQUEFACTION FACILITY[1]

Operation/Emission Source/Stream	Characterization of Emission	Summary of Emission Control Choices
Residue Gasification	See 8.21.2.1, in text.	
Auxiliary Processes		
Power and steam generation	See Section 1.1.	
Wastewater system	Volatile organics, acid gases, ammonia and cyanides, which evolve from various waste water collection and treating systems.	Enclosure of the waste water system and venting gases from system to scrubbers or incinerators.
Cooling towers	Any chemical in the facility can leak to cooling water system from leaking heat exchangers and can be stripped to the atmosphere in the cooling tower.	Good heat exchanger maintenance and surveillance of cooling water quality.
Fugitives	All organic and gaseous compounds in plant can leak from valves, flanges, seals and sample ports. This may be the largest source of hazardous organics.	Good housekeeping, frequent maintenance and selection of durable components are major control techniques.

air. Cooling towers are usually minor emission sources, unless the cooling water is contaminated.

8.21.2.2 Liquefaction - The potential exists for generation of significant levels of atmospheric pollutants from every major operation in a coal liquefaction facility. These pollutants include coal dust, combustion products, fugitive organics and fugitive gases. The fugitive organics and gases could include carcinogenic polynuclear organics and toxic gases such as metal carbonyls, hydrogen sulfides, ammonia, sulfurous gases, and cyanides. Many studies are currently underway to characterize these emissions and to establish effective control methods. Table 8.21-2 presents information now available on liquefaction emissions.

Emissions from coal preparation include coal dust from the many handling operations and combustion products from the drying operation. The most significant pollutant from these operations is the coal dust from crushing, screening and drying activities. Wetting down the surface of the coal, enclosing the operations, and venting effluents to a scrubber or fabric filter are effective means of particulate control.

A major source of emissions from the coal dissolution and liquefaction operation is the atmospheric vent on the slurry mix tank. The slurry mix tank is used for mixing feed coal and recycle solvent. Gases dissolved in the recycle solvent stream under pressure will flash from the solvent as it enters the unpressurized slurry mix tank. These gases can contain hazardous volatile organics and acid gases. Control techniques proposed for this source include scrubbing, incineration or venting to the combustion air supply for either a power plant or a process heater.

Emissions from process heaters fired with waste process gas or waste liquids will consist of standard combustion products. Industrial combustion emission sources and available controls are discussed in Section 1.1.

The major emission source in the product separation and purification operations is the sulfur recovery plant tail gas. This can contain significant levels of acid or sulfurous gases. Emission factors and control techniques for sulfur recovery tail gases are discussed in Section 5.18.

Emissions from the residue gasifier used to supply hydrogen to the system are very similar to those for coal gasifiers previously discussed in this Section.

Emissions from auxiliary processes include combustion products from onsite steam/electric power plant and volatile emissions from the wastewater system, cooling towers and fugitive emission sources. Volatile emissions from cooling towers, wastewater systems and fugitive emission sources possibly can include every chemical compound present in the plant. These sources will be the most significant and most difficult

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to control in a coal liquefaction facility. Compounds which can be present include hazardous organics, metal carbonyls, trace elements such as mercury, and toxic gases such as CO, H_2S, HCN, NH_3, COS and CS_2.

Emission controls for wastewater systems involve minimizing the contamination of water with hazardous compounds, enclosing the waste water systems, and venting the wastewater systems to a scrubbing or incineration system. Cooling tower controls focus on good heat exchanger maintenance, to prevent chemical leaks into the system, and on surveillance of cooling water quality. Fugitive emissions from various valves, seals, flanges and sampling ports are individually small but collectively very significant. Diligent housekeeping and frequent maintenance, combined with a monitoring program, are the best controls for fugitive sources. The selection of durable low leakage components, such as double mechanical seals, is also effective.

References for Section 8.21

1. C. E. Burklin and W. J. Moltz, Energy Resource Development System, EPA Contract No. 68-01-1916, Radian Corporation and The University of Oklahoma, Austin, TX, September 1978.

2. E. C. Cavanaugh, et al., Environmental Assessment Data Base for Low/Medium-BTU Gasification Technology, Volume 1, EPA-600/7-77-125a, U. S. Environmental Protection Agency, Research Triangle Park, NC, November 1977.

3. P. W. Spaite and G. C. Page, Technology Overview: Low- and Medium-BTU Coal Gasification Systems, EPA-600/7-78-061, U.S. Environmental Protection Agency, Research Triangle Park, NC, March 1978.

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8.22 TACONITE ORE PROCESSING

8.22.1 General[1,2]

More than two thirds of the iron ore produced in the United States for making iron consists of taconite concentrate pellets. Taconite is a low grade iron ore, largely from deposits in Minnesota and Michigan, but from other areas as well. Processing of taconite consists of crushing and grinding the ore to liberate ironbearing particles, concentrating the ore by separating the particles from the waste material (gangue), and pelletizing the iron ore concentrate. A simplified flow diagram of these processing steps is shown in Figure 8.22-1.

Liberation - The first step in processing crude taconite ore is crushing and grinding. The ore must be ground to a particle size sufficently close to the grain size of the ironbearing mineral, to allow for a high degree of mineral liberation. Most of the taconite used today requires very fine grinding. The grinding is normally performed in three or four stages of dry crushing, followed by wet grinding in rod mills and ball mills. Gyratory crushers are generally used for primary crushing, and cone crushers are used for secondary and tertiary fine crushing. Intermediate vibrating screens remove undersize material from the feed to the next crusher and allow for closed circuit operation of the fine crushers. The rod and ball mills are also in closed circuit with classification systems such as cyclones. An alternative is to feed some coarse ores directly to wet or dry semiautogenous or autogenous grinding mills, then to pebble or ball mills. Ideally, the liberated particles of iron minerals and barren gangue should be removed from the grinding circuits as soon as they are formed, with larger particles returned for further grinding.

Concentration - As the iron ore minerals are liberated by the crushing steps, the ironbearing particles must be concentrated. Since only about 33 percent of the crude taconite becomes a shipable product for iron making, a large amount of gangue is generated. Magnetic separation and flotation are most commonly used for concentration of the taconite ore.

Crude ores in which most of the recoverable iron is magnetite (or, in rare cases, maghemite) are normally concentrated by magnetic separation. The crude ore may contain 30 to 35 percent total iron by assay, but theoretically only about 75 percent of this is recoverable magnetite. The remaining iron becomes part of the gangue.

Nonmagnetic taconite ores are concentrated by froth flotation or a combination of selective flocculation and flotation. The method is determined by the differences in surface activity between the iron and gangue particles. Sharp separation is often difficult.

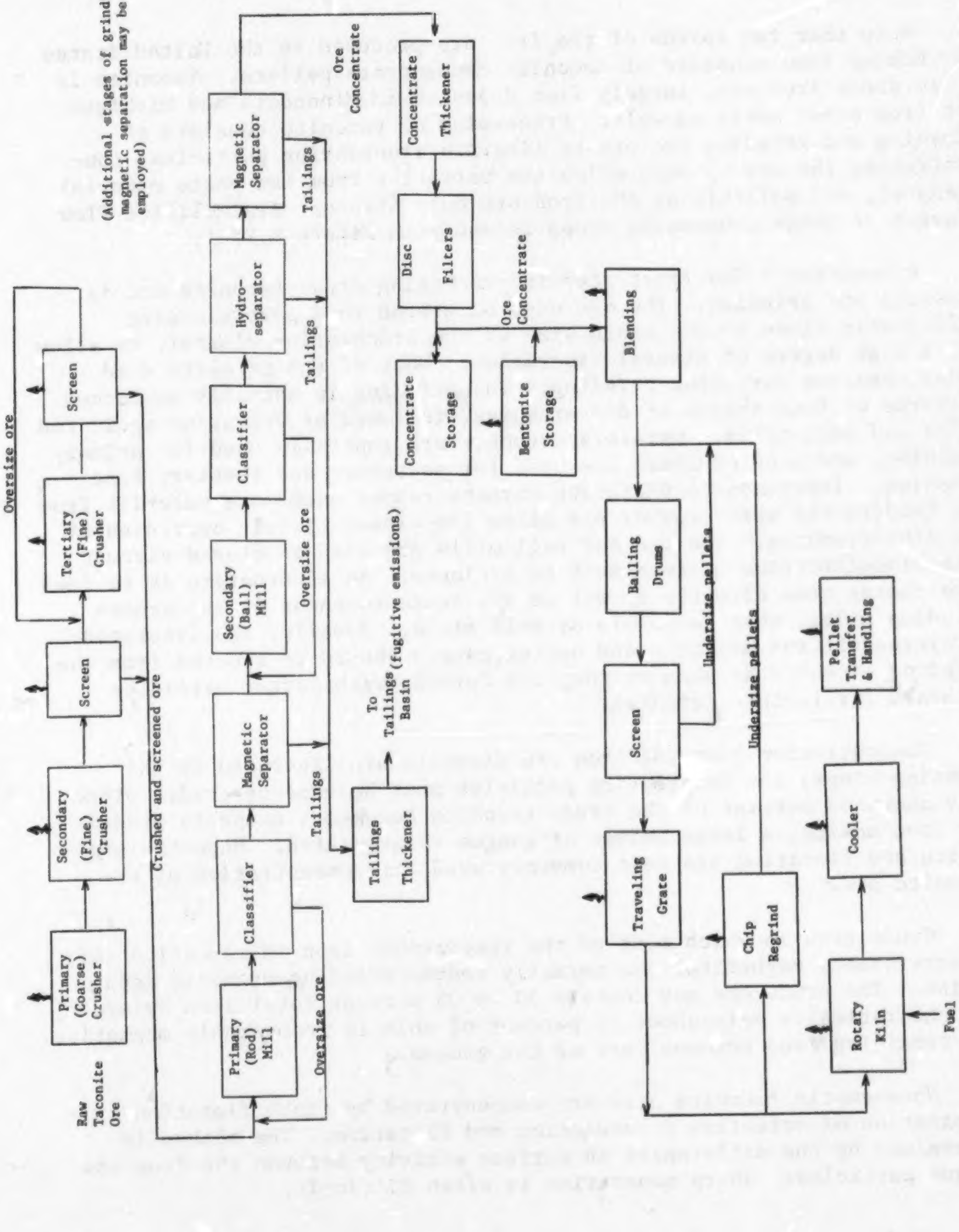
Raw Taconite Ore
Primary (Coarse) Crusher
Secondary (Fine) Crusher
Screen
Tertiary (Fine) Crusher
Screen
Oversize ore
Crushed and screened ore
Primary (Rod) Mill
Oversize ore
Classifier
Magnetic Separator
Tailings
Secondary (Ball) Mill
Oversize ore
Classifier
Oversize ore
Tailings
Hydro-separator
Tailings
Magnetic Separator
Tailings
Concentrate Thickener
Ore Concentrate
(Additional stages of grinding and magnetic separation may be employed)
Tailings Thickener
To Tailings Basin (fugitive emissions)
Disc Filters
Ore Concentrate
Blending
Concentrate Storage
Bentonite Storage
Balling Drums
Undersize pellets
Screen
Undersize pellets
Traveling Grate
Chip Regrind
Rotary Kiln
Fuel
Cooler
Pellet Transfer & Handling

Figure 8.22-1. Taconite ore processing plant.
(Process emissions are indicated by ↑. Emissions indicated between boxes are from ore transfer.)

In the vertical shaft furnace, the wet green balls are distributed evenly over the top of the slowly descending bed of pellets. A rising stream of gas of controlled temperature and composition flows counter to the descending bed of pellets. Auxiliary fuel combustion chambers supply hot gases midway between the top and bottom of the furnace. In the straight grate apparatus, a continuous bed of agglomerated green pellets is carried through various up and down flows of gases at different temperatures. The grate/kiln apparatus consists of a continuous traveling grate followed by a rotary kiln. Pellets indurated by the straight grate apparatus are cooled on an extension of the grate or in a separate cooler. The grate/kiln product must be cooled in a separate cooler, usually an annular cooler with countercurrent airflow.

8.22.2 Emissions and Controls[1,2]

Emission sources from processing operations are indicated in Figure 8.22-1. Particulate emissions also arise from ore transfer operations. Uncontrolled emission factors for the major sources are presented in Table 8.22-1, and control efficiences in Table 8.22-2.

The taconite ore is handled dry through the crushing stages. All crushers, size classification screens and conveyor transfer points are major points of particulate emissions. Crushed ore is normally ground in wet rod and ball mills. A few plants, however, use dry autogenous or semiautogenous grinding and have higher emissions than do conventional plants. The ore remains wet through the rest of the beneficiation process, so particulate emissions after crushing are generally insignificant.

The first source of emissions in the pelletizing process is the transfer and blending of bentonite. There are no other significant emissions in the balling section, since the iron ore concentrate is normally too wet to cause appreciable dusting. Additional emission points in the pelletizing process include the main waste gas stream from the indurating furnace, pellet handling, furnace transfer points (grate feed and discharge), and, for plants using the grate/kiln furnace, annular coolers. In addition, tailings basins and unpaved roadways can be sources of fugitive emissions.

Fuel used to fire the indurating furnace generates low levels of SO_2 emissions. For a natural gas fired furnace, these emissions are about 0.06 pounds of SO_2 per ton of pellets produced (0.03 kg/MT). Higher SO_2 emissions (about 0.12 - 0.14 lb/ton, or 0.6 - 0.7 kg/MT) would result from an oil or coal fired furnace.

Particulate emissions from taconite ore processing plants are controlled by a variety of devices, including cyclones, multiclones, rotoclones, scrubbers, baghouses and electrostatic precipitators. Water sprays are also used to suppress dusting. Annular coolers are generally left uncontrolled, because their mass loadings of particulates are small, typically less than 0.05 gram/scf (0.11 g/m^3).

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Various combinations of magnetic separation and flotation may be used to concentrate ores containing various iron minerals (magnetite and hematite, or maghemite) or wide ranges of mineral grain sizes. Flotation is also often used as a final polishing operation on magnetic concentrates.

Pelletization - Iron ore concentrates must be coarser than about No. 10 mesh to be acceptable as blast furnace feed without further treatment. The finer concentrates are agglomerated into small "green" pellets. This is normally accomplished by tumbling moistened concentrate with a balling drum or balling disc. A binder additive, usually powdered bentonite, may be added to the concentrate to improve ball formation and the physical qualities of the "green" balls. The bentonite is lightly mixed with the carefully moistened feed at 10 to 20 pounds per ton (4.5 - 9 kg/MT).

The pellets are hardened by a procedure called induration, the drying and heating of the green balls in an oxidizing atmosphere at incipient fusion temperature (2350 - 2550°F [1290 - 1400°C] depending on the composition of the balls) for several minutes and then cooling. Four general types of indurating apparatuses are currently used. These are the vertical shaft furnace, the straight grate, the circular grate and the grate/kiln. Most of the large plants and new plants use the grate/kiln. Natural gas is most commonly used for pellet induration now, but probably not in the future. Heavy oil is being used at a few plants, and coal may be used at future plants.

Table 8.22-1. UNCONTROLLED PARTICULATE EMISSION FACTORS FOR TACONITE ORE PROCESSING[a]

EMISSION FACTOR RATING: D

Source	Emissions[b,c]	
	lb/ton	kg/MT
Fine crushing	79.8	39.9
Waste gas	29.2	14.6
Pellet handling	3.4	1.7
Grate discharge	1.32	0.66
Grate feed	0.64	0.32
Bentonite blending	0.22	0.11
Coarse crushing	0.20	0.10
Ore transfer	0.10	0.05
Bentonite transfer	0.04	0.02

[a] Emission factors expressed as units per unit weight of pellets produced.
[b] Median values.
[c] Reference 1.

Table 8.22-2. CONTROL EFFICIENCIES FOR VARIOUS COMBINATIONS OF CONTROL DEVICES AND SOURCES[a]

Control device	Coarse crushing	Ore transfer	Fine crushing	Bentonite transfer	Bentonite blending	Grate feed	Grate discharge	Waste gas	Pellet handling
Scrubber	95(10)f 91.6(4)f 99(2)m	99.5(18)f 99(5)f 97(4)m 99(1)m	99.5(5)f 99.6(6)f 97(10)m 97(19)e	98(1)f	98.7(1)f 99.3(1)f	98.7(2)f 98(1)m 99(5)e	99.3(2)f 99(5)e 98(1)e	98.5(1)e 89(1)e	99.3(2)f 99.7(1)f 99(2)f 97.5(1)e
Cyclone	85(1)f	95(2)e						95-98(56)f	
Multiclone	92(2)f 88(2)f							95-98(2)f	
Rotoclone	91.6(4)f	98(1)f	99.7(7)f 98.3(4)f						98(1)e
Bag collector	99(2)m 99.9(2)m 99(4)e 99.9(2)e			99(8)e	99(2)f 99.7(1)f				
Electrostatic precipitator								98.9(2)f 98.8(1)e	
Dry mechanical collector	85(1)f	85(1)f							
Centrifugal collector						88(1)f 98(1)e 99.4(1)e	88(1)f 99.4(1)e		

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[a] Reference 1. Control efficiencies are expressed as percent reduction. Numbers in parentheses are the number of indicated combinations with the stated efficiency. The letters m, f, e denote whether the stated efficiencies were based upon manufacturer's rating (m), field testing (f), or estimations (e). Blanks indicate that no such combinations of source and control technology are known to exist, or that no data on the efficiency of the combination are available.

References for Section 8.22

1. John P. Pilney and Gordon V. Jorgensen, Emissions from Iron Ore Mining, Beneficiation and Pelletization, Volume 1, EPA Contract No. 68-02-2113, Midwest Research Institute, Minnetonka, MN, June 1978.

2. A. K. Reed, Standard Support and Environmental Impact Statement for the Iron Ore Beneficiation Industry (Draft), EPA Contract No. 68-02-1323, Battelle Columbus Laboratories, Columbus, OH, December 1976.

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10.3 PLYWOOD VENEER AND LAYOUT OPERATIONS

10.3.1 General[1-3]

Plywood is a building material consisting of veneers (thin wood layers or plies) bonded with an adhesive. The outer layers (faces) surround a core which is usually lumber, veneer or particle board. Plywood uses are many, including wall siding, sheathing, roof decking, concrete formboards, floors, and containers. Most plywood is made from Douglas Fir or other softwoods, and the majority of plants are in the Pacific Northwest. Hardwood veneers make up only a very small portion of total production.

In the manufacture of plywood, logs are sawed to the desired length, debarked and peeled into veneers of uniform thickness. Veneer thicknesses of less than one half inch or one centimeter are common. These veneers are then transported to veneer dryers with one or more decks, to reduce their moisture content. Dryer temperatures are held between about 300 and 400°F (150 - 200°C). After drying, the plies go through the veneer layout operation, where the veneers are sorted, patched and assembled in perpendicular layers, and a thermosetting resin adhesive applied. The veneer assembly is then transferred to a hot press where, under pressure and steam heat, the product is formed. Subsequently, all that remains is trimming, face sanding, and possibly some finishing treatment to enhance the usefulness of the product. Plywood veneer and layout operations are shown in Figure 10.3-1.

10.3.2 Emissions and Controls [2-8]

Emissions from the manufacture of plywood include particulate matter and organic compounds. The main source of emissions is the veneer dryer, with other sources producing negligible amounts of organic compound emissions or fugitive emissions. The log steaming and veneer drying operations produce combustion products, and these emissions depend entirely on the type of fuel and equipment used.

Uncontrolled fugitive particulate matter, in the form of sawdust and other small wood particles, comes primarily from the plywood cutting and sanding operations. To be considered additional sources of fugitive particulate emissions are log debarking, log sawing and sawdust handling. The dust that escapes into the air from sanding, sawing and other woodworking operations may be controlled by collection in an exhaust system and transport through duct work to a sized cyclone. Section 10.4 discusses emissions from such woodworking waste collection operations. Estimates of uncontrolled particulate emission factors for log debarking and sawing, sawdust pile handling, and plywood sanding and cutting are given in Table 10.3-1. From the veneer dryer, and at stack temperatures, the only particulate emissions are small amounts of wood fiber particles in concentrations of less than 0.002 grams per dry standard cubic foot.

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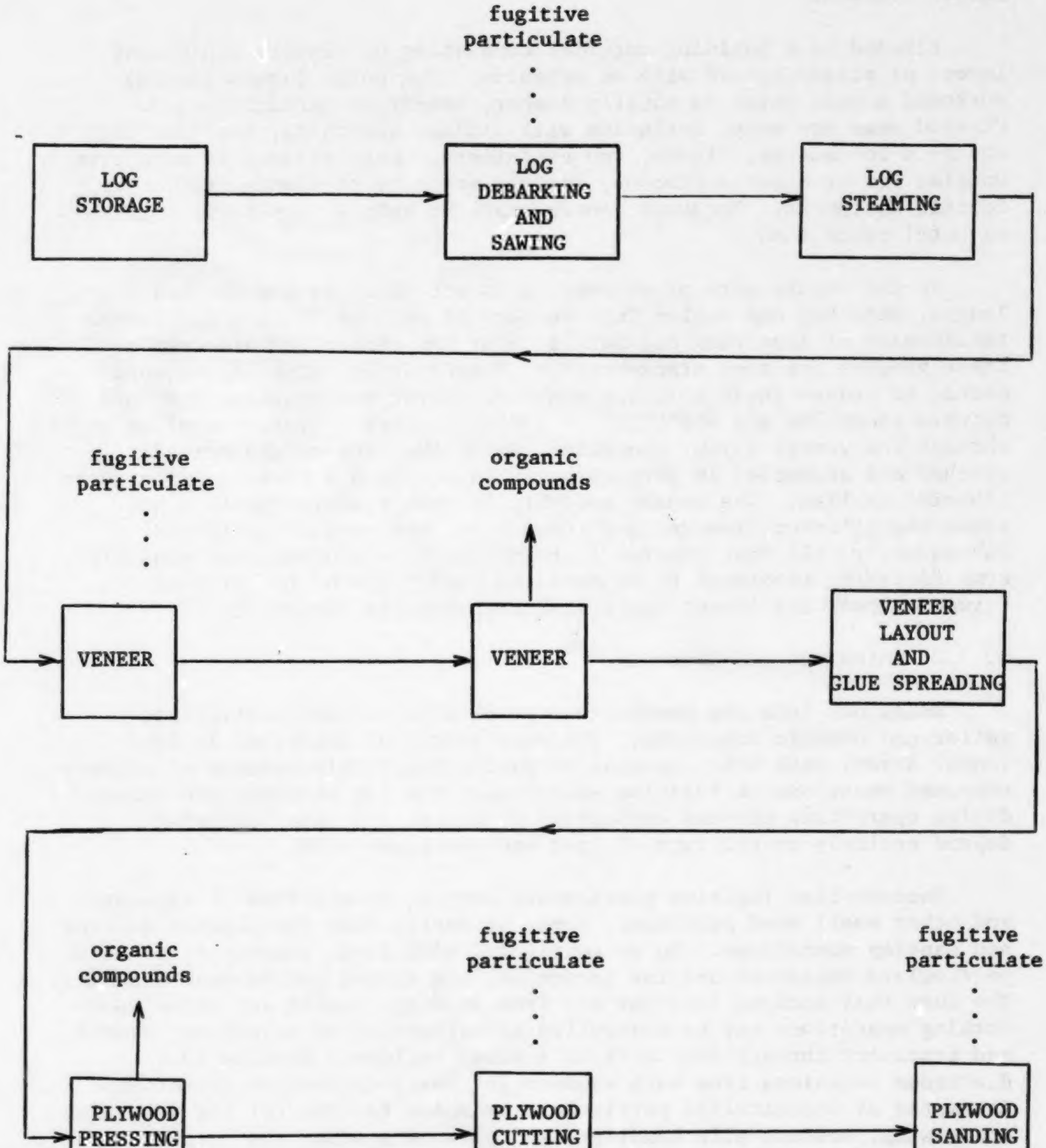
fugitive particulate
LOG STORAGE
LOG DEBARKING AND SAWING
LOG STEAMING
fugitive particulate
organic compounds
VENEER
VENEER
VENEER LAYOUT AND GLUE SPREADING
organic compounds
fugitive particulate
fugitive particulate
PLYWOOD PRESSING
PLYWOOD CUTTING
PLYWOOD SANDING

Figure 10.3-1. Plywood veneer and layout operations.[4,5]

Table 10.3-1. UNCONTROLLED FUGITIVE PARTICULATE EMISSION FACTORS FOR PLYWOOD VENEER AND LAYOUT OPERATONS

EMISSION FACTOR RATING: E

Source	Particulates	
Log debarking[a]	0.024 lb/ton	0.012 kg/MT
Log sawing[a]	0.350 lb/ton	0.175 kg/MT
Sawdust handling[b]	1.0 lb/ton	0.5 kg/MT
Veneer lathing[c]	NA	NA
Plywood cutting and sanding[d]	0.1 lb/ft^2	0.05 kg/m^2

[a] Reference 7. Emission factors are expressed as units per unit weight of logs processed.

[b] Reference 7. Emission factors are expressed as units per unit weight of sawdust handled, including sawdust pile loading, unloading and storage.

[c] Estimates not available.

[d] Reference 5. Emission factors are expressed as units per surface area of plywood produced. These factors are expressed as representative values for estimated values ranging from 0.066 to 0.132 lb/ft^2 (0.322 to 0.644 kg/m^2).

The major pollutants emitted from veneer dryers are organic compounds. The quantity and type of organics emitted vary, depending on the wood species and on the dryer type and its method of operation. There are two discernable fractions which are released, condensibles and volatiles. The condensible organic compounds consist largely of wood resins, resin acids and wood sugars, which cool outside the stack to temperatures below 70°F (21°C) and combine with water vapor to form a blue haze, a water plume or both. This blue haze may be eliminated by condensing the organic vapors in a finned tube matrix heat exhanger condenser. The other fraction, volatile organic compounds, is comprised of terpenes and natural gas components (such as unburned methane), the latter occurring only when gas fired dryers are used. The amounts of organic compounds released because of adhesive use during the plywood pressing operation are negligible. Uncontrolled organic process emission factors are given in Table 10.3-2.

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Table 10.3-2. UNCONTROLLED ORGANIC COMPOUND PROCESS EMISSION FACTORS FOR PLYWOOD VENEER DRYERS[a]

EMISSION FACTOR RATING: B

	Volatile Organic Compounds		Condensible Organic Compounds	
Species	$lb/10^4\ ft^2$	$kg/10^4\ m^2$	$lb/10^4\ ft^2$	$kg/10^4\ m^2$
Douglas Fir				
sapwood				
steam fired	0.45	2.3	4.64	23.8
gas fired	7.53	38.6	2.37	12.1
heartwood	1.30	6.7	3.18	16.3
Larch	0.19	1.0	4.14	21.2
Southern pine	2.94	15.1	3.70	18.9
Other[b]	0.03-3.00	0.15-15.4	0.5-8.00	2.56-41.0

[a] Reference 2. Emission factors are expressed in pounds of pollutant per 10,000 square feet of 3/8 inch thick veneer dried, and kilograms of pollutant per 10,000 square meters of 1 centimeter thick veneer dried. All dryers are steam fired unless otherwise specified.

[b] These ranges of factors represent results from one source test for each of the following species (in order from least to greatest emissions): Western Fir, Hemlock, Spruce, Western Pine and Ponderosa Pine.

References for Section 10.3

1. C.B. Hemming, "Plywood", Kirk-Othmer Encyclopedia of Chemical Technology, Second Edition, Volume 15, John Wiley & Sons, Inc., New York, NY, 1968, pp. 896-907.

2. F. L. Monroe, et al., Investigation of Emissions from Plywood Veneer Dryers, Washington State University, Pullman, WA, February 1972.

3. Theodore Baumeister, ed., "Plywood", Standard Handbook for Mechanical Engineers, Seventh Edition, McGraw-Hill, New York, NY, 1967, pp. 6-162 - 6-169.

4. Allen Mick and Dean McCargar, Air Pollution Problems in Plywood, Particleboard, and Hardboard Mills in the Mid-Willamette Valley, Mid-Willamette Valley Air Pollution Authority, Salem, OR, March 24, 1969.

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5. Controlled and Uncontrolled Emission Rates and Applicable Limitations for Eighty Processes, Second Printing, EPA-340/1-78-004, U.S. Environmental Protection Agency, Research Triangle Park, NC, April 1978, pp. X-1 - X-6.

6. John A. Danielson, ed., Air Pollution Engineering Manual, AP-40, Second Edition, U.S. Environmental Protection Agency, Research Triangle Park, NC, May 1973, pp. 372-374.

7. Assessment of Fugitive Particulate Emission Factors for Industrial Processes, EPA-450/3-78-107, U.S. Environmental Protection Agency, Research Triangle Park, NC, September 1978.

8. C. Ted Van Decar, "Plywood Veneer Dryer Control Device", Journal of the Air Pollution Control Association, 22:968, December 1972.

10.4 WOODWORKING WASTE COLLECTION OPERATIONS

10.4.1 General[1-5]

Woodworking, as defined in this section, includes any operation that involves the generation of small wood waste particles (shavings, sanderdust, sawdust, etc.) by any kind of mechanical manipulation of wood, bark, or wood byproducts. Common woodworking operations include sawing, planing, chipping, shaping, moulding, hogging, lathing, and sanding. Woodworking operations are found in numerous industries, such as sawmills, plywood, particleboard, and hardboard plants, and furniture manufacturing plants.

Most plants engaged in woodworking employ pneumatic transfer systems to remove the generated wood waste from the immediate proximity of each woodworking operation. These systems are necessary as a housekeeping measure to eliminate the vast quantity of waste material that would otherwise accumulate. They are also a convenient means of transporting the waste material to common collection points for ultimate disposal. Large diameter cyclones have historically been the primary means of separating the waste material from the airstreams in the pneumatic transfer systems, although baghouses have recently been installed in some plants for this purpose.

The waste material collected in the cyclones or baghouses may be burned in wood waste boilers, utilized in the manufacture of other products (such as pulp or particleboard), or incinerated in conical (teepee/wigwam) burners. The latter practice is declining with the advent of more stringent air pollution control regulations and because of the economic attractiveness of utilizing wood waste as a resource.

10.4.2 Emissions[1-6]

The only pollutant of concern in woodworking waste collection operations is particulate matter. The major emission points are the cyclones utilized in the pneumatic transfer systems. The quantity of particulate emissions from a given cyclone will depend on the dimensions of the cyclone, the velocity of the airstream, and the nature of the operation generating the waste. Typical large diameter cyclones found in the industry will only effectively collect particles greater than 40 micrometers in diameter. Baghouses, when employed, collect essentially all of the waste material in the airstream. The wastes from numerous pieces of equipment often feed into the same cyclone, and it is common for the material collected in one or several cyclones to be conveyed to another cyclone. It is also possible for portions of the waste generated by a single operation to be directed to different cyclones.

Because of this complexity, it is useful when evaluating emissions from a given facility to consider the waste handling cyclones as air pollution sources instead of the various woodworking operations that actually generate the particulate matter. Emission factors for typical large diameter cyclones utilized for waste collection in woodworking operations are given in Table 10.4-1.

Emission factors for wood waste boilers, conical burners, and various drying operations–often found in facilities employing woodworking operations–are given in Sections 1.6, 2.3, 10.2, and 10.3.

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Table 10.4.1. PARTICULATE EMISSION FACTORS FOR LARGE DIAMETER CYCLONES IN WOODWORKING WASTE COLLECTION SYSTEMS[a]

EMISSION FACTOR RATING: D

Types of waste handled	Particulate emissions[b,c]			
	gr/scf	g/Nm³	lb/hr	kg/hr
Sanderdust[d]	0.055 (0.005-0.16)	0.126 (0.0114-0.37)	5 (0.2-30.0)	2.3 (0.09-13.6)
Other[e]	0.03 (0.001-0.16)	0.07 (0.002-0.37)	2 (0.03-24.0)	0.91 (0.014-10.9)

[a] Typical waste collection cyclones range from 4 to 16 feet (1.2 to 4.9 meters) in diameter and employ airflows ranging from 2,000 to 26,000 standard cubic feet (57 to 740 normal cubic meters) per minute. Note: if baghouses are used for waste collection, particulate emissions will be negligible.

[b] References 1 through 3.

[c] Observed value ranges are in parentheses.

[d] These factors should be used whenever waste from sanding operations is fed directly into the cyclone in question.

[e] These factors should be used for cyclones handling waste from all operations other than sanding. This includes cyclones that handle waste (including sanderdust) already collected by another cyclone.

References for Section 10.4

1. Source test data supplied by Robert Harris, Oregon Department of Environmental Quality, Portland, OR, September 1975.

2. J.W. Walton, *et al.*, "Air Pollution in the Woodworking Industry", Presented at the 68th Annual Meeting of the Air Pollution Control Association, Boston, MA, June 1975.

3. J.D. Patton and J.W. Walton, "Applying the High Volume Stack Sampler To Measure Emissions from Cotton Gins, Woodworking Operations, and Feed and Grain Mills", Presented at 3rd Annual Industrial Air Pollution Control Conference, Knoxville, TN, March 29-30, 1973.

4. C.F. Sexton, "Control of Atmospheric Emissions from the Manufacturing of Furniture", Presented at 2nd Annual Industrial Air Pollution Control Conference, Knoxville, TN, April 20-21, 1972.

5. A. Mick and D. McCargar, "Air Pollution Problems in Plywood, Particleboard, and Hardboard Mills in the Mid-Willamette Valley", Mid-Williamette Valley Air Pollution Authority, Salem, OR, March 24, 1969.

6. Information supplied by the North Carolina Department of Natural and Economic Resources, Raleigh, NC, December 1975.

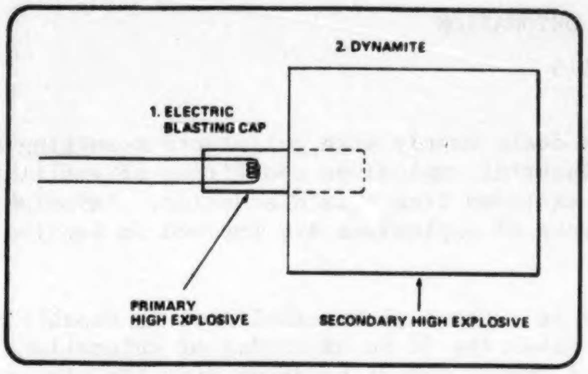
11.3 EXPLOSIVES DETONATION

11.3.1 General [1-5]

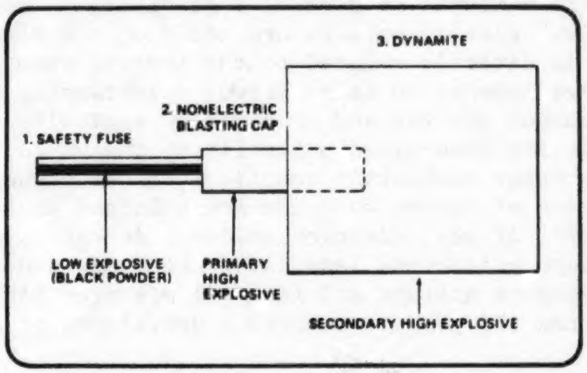
This section deals mainly with pollutants resulting from the detonation of industrial explosives and firing of small arms. Military applications are excluded from this discussion. Emissions associated with the manufacture of explosives are treated in Section 5.6, Explosives.

An explosive is a chemical material that is capable of extremely rapid combustion resulting in an explosion or detonation. Since an adequate supply of oxygen cannot be drawn from the air, a source of oxygen must be incorporated into the explosive mixture. Some explosives, such as trinitrotoluene (TNT), are single chemical species, but most explosives are mixtures of several ingredients. "Low explosive" and "high explosive" classifications are based on the velocity of explosion, which is directly related to the type of work the explosive can perform. There appears to be no direct relationship between the velocity of explosions and the end products of explosive reactions. These end products are determined primarily by the oxygen balance of the explosive. As in other combustion reactions, a deficiency of oxygen favors the formation of carbon monoxide and unburned organic compounds and produces little, if any, nitrogen oxides. An excess of oxygen causes more nitrogen oxides and less carbon monoxide and other unburned organics. For ammonium nitrate and fuel oil mixtures (ANFO), a fuel oil content of more than 5.5 percent creates a deficiency of oxygen.

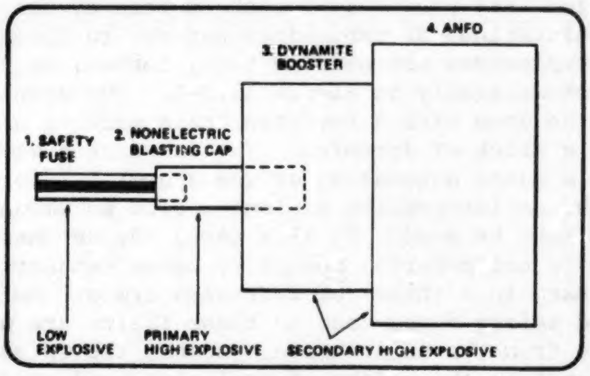
There are hundreds of different explosives, with no universally accepted system for classifying them. The classification used in Table 11.3-1 is based on the chemical composition of the explosives, without regard to other to other properties, such as rate of detonation, which relate to the applications of explosives but not to their specific end products. Most explosives are used in two-, three-, or four-step trains that are shown schematically in Figure 11.3-1. The simple removal of a tree stump might be done with a two-step train made up of an electric blasting cap and a stick of dynamite. The detonation wave from the blasting cap would cause detonation of the dynamite. To make a large hole in the earth, an inexpensive explosive such as ammonium nitrate and fuel oil (ANFO) might be used. In this case, the detonation wave from the blasting cap is not powerful enough to cause detonation, so a booster must be used in a three- or four-step train. Emissions from the blasting caps and safety fuses used in these trains are usually small compared to those from the main charge, because the emissions are roughly proportional to the weight of explosive used, and the main charge makes up most of the total weight. No factors are given for computing emissions from blasting caps or fuses, because these have not been measured, and because the uncertainties are so great in estimating emissions from the main and booster charges that a precise estimate of all emissions is not practical.


2. DYNAMITE
1. ELECTRIC BLASTING CAP
PRIMARY HIGH EXPLOSIVE
SECONDARY HIGH EXPLOSIVE

a. Two-step explosive train


3. DYNAMITE
2. NONELECTRIC BLASTING CAP
1. SAFETY FUSE
LOW EXPLOSIVE (BLACK POWDER)
PRIMARY HIGH EXPLOSIVE
SECONDARY HIGH EXPLOSIVE

b. Three-step explosive train


4. ANFO
3. DYNAMITE BOOSTER
1. SAFETY FUSE
2. NONELECTRIC BLASTING CAP
LOW EXPLOSIVE
PRIMARY HIGH EXPLOSIVE
SECONDARY HIGH EXPLOSIVE

c. Four-step explosive train

Figure 11.3-1. Two-, three-, and four-step explosive trains.

Table 11.3-1. EMISSION FACTORS FOR DETONATION OF EXPLOSIVES (EMISSION FACTOR RATING: D)

Explosive	Composition	Uses	Carbon Monoxide[a]		Nitrogen Oxides[a]		Methane[b]		Other[a]		
			kg/MT	lb/ton	kg/MT	lb/ton	kg/MT	lb/ton	Pollutant	kg/MT	lb/ton
Black powder[2]	75/15/10; potassium (sodium) nitrate/charcoal/sulfur	delay fuses	85 (38-120)	170 (76-240)	NA	NA	2.1 (0.3-4.9)	4.2 (0.6-9.7)	H_2S	12 (0-37)	24 (0-73)
Smokeless Powder[2]	nitrocellulose (sometimes with other materials)	small arms propellant	38 (34-42)	77 (68-84)	NA	NA	0.6 (0.4-0.6)	1.1 (0.7-1.5)	H_2S Pb	10 (10-11) c	21 (20-21) c
Dynamite, Straight[2]	20-60% nitroglycerine/ sodium nitrate/wood pulp/ calcium carbonate	rarely used	141 (44-262)	281 (87-524)	NA	NA	1.3 (0.3-2.8)	2.5 (0.6-5.6)	H_2S	3 (0-7)	6 (0-15)
Dynamite, Ammonia[2]	20-60% nitroglycerine/ ammonium nitrate/sodium nitrate/wood pulp	quarry work stump blasting	32 (23-64)	63 (46-128)	NA	NA	0.7 (0.3-1.1)	1.3 (0.6-2.1)	H_2S	16 (9-19)	31 (19-37)
Dynamite, Gelatin[2]	20-100% nitroglycerine	demolition, construction work, blasting in mines	52 (13-110)	104 (26-220)	26 (4-59)	53 (8-119)	0.3 (0.1-0.8)	0.7 (0.3-1.7)	H_2S SO_2	2 (0-3) 1 (0-8)	4 (0-6) 1 (1-16)
ANFO[4,5]	ammonium nitrate with 5.8-8% fuel oil	construction work, blasting in mines	34	67	8	17	NA	NA	SO_2	1 (0-2)	2 (1-3)
TNT[2]	trinitrotoluene	main charge in artillery projectiles, mortar rounds, etc.	398 (324-472)	796 (647-944)	NA	NA	7.2 (6.6-7.7)	14.3 (13.2-15.4)	NH_3 HCN C_2H_2 C_2H_6	14 (14-15) 13 (11-16) 61 0.5	29 (27-30) 27 (22-32) 121 1.1
RDX[3]	$(CH_2)_3N_3(NO_2)_3$ cyclotrimethylenetrinitroamine	booster	98[d] (2.8-277)	196[d] (5.6-554)	NA	NA	NA	NA	NH_3	22[d] (12-61)	44[d] (24-122)
PETN[2]	$C(CH_2ONO_2)_4$ pentaerythritol tetranitrate	booster	149 (138-160)	297 (276-319)	NA	NA	NA	NA	NH_3	1.3 (0-25)	2.5 (0-5)

[a] Based on experiments carried out prior to 1930 except in the case of ANFO, TNT and PETN. NA = not available.

[b] The factors apply to the chemical species, methane. They do not represent total VOC expressed as methane. Studies were carried out more than 40 years ago. NA = not available.

[c] Greater than 6 mg per 158 grain projectile (0.6 kg/MT, 1.2 lb/ton).

[d] These factors are derived from theoretical calculations - not from experimental data.

11.3.3 Emissions and Controls[2,4-6]

Carbon monoxide is the pollutant produced in greatest quantity from explosives detonation. TNT, an oxygen deficient explosive, produces more CO than most dynamites, which are oxygen balanced. But all explosives produce measurable amounts of CO. Particulates are produced as well, but such large quantities of particulate are generated in the shattering of the rock and earth by the explosive that the quantity of particulates from the explosive charge cannot be distinguished. Nitrogen oxides (both NO and NO_2) are formed, but only limited data are available on these emissions. Oxygen deficient explosives are said to produce little or no nitrogen oxides, but there is only a small body of data to confirm this. Unburned hydrocarbons also result from explosions, but in most instances, methane is the only species that has been reported.

Hydrogen sulfide, hydrogen cyanide and ammonia all have been reported as products of explosives use. Lead is emitted from the firing of small arms ammunition with lead projectiles and/or lead primers, but the explosive charge does not contribute to the lead emissions.

The emissions from explosives detonation are influenced by many factors such as explosive composition, product expansion, method of priming, length of charge, and confinement. These factors are difficult to measure and control in the field and are almost impossible to duplicate in a laboratory test facility. With the exception of a few studies in underground mines, most studies have been performed in laboratory test chambers that differ substantially from the actual environment. Any estimates of emissions from explosives use must be regarded as approximations that cannot be made more precise, because explosives are not used in a precise, reproducible manner.

To a certain extent, emissions can be altered by changing the composition of the explosive mixture. This has been practiced for many years to safeguard miners who must use explosives. The U. S. Bureau of Mines has a continuing program to study the products from explosives and to identify explosives that can be used safely underground. Lead emissions from small arms use can be controlled by using jacketed soft point projectiles and special leadfree primers.

Emission factors are given in Table 11.3-1.

References for Section 11.3

1. C. R. Newhouser, Introduction to Explosives, National Bomb Data Center, International Association of Chiefs of Police, Gaithersburg, MD (undated).

2. Roy V. Carter, "Emissions from the Open Burning or Detonation of Explosives", Presented at the 71st Annual Meeting of the Air Pollution Control Association, Houston, TX, June 1978.

3. Melvin A. Cook, The Science of High Explosives, Reinhold Publishing Corporation, New York, 1958.

4. R. F. Chaiken, et al., Toxic Fumes from Explosives: Ammonium Nitrate Fuel Oil Mixtures, Bureau of Mines Report of Investigations 7867, U. S. Department of Interior, Washington, DC, 1974.

5. Sheridan J. Rogers, Analysis of Noncoal Mine Atmospheres: Toxic Fumes from Explosives, Bureau of Mines, U. S. Department of Interior, Washington, DC, May 1976.

6. A. A. Juhasz, "A Reduction of Airborne Lead in Indoor Firing Ranges by Using Modified Ammunition", Special Publication 480-26, Bureau of Standards, U. S. Department of Commerce, Washington, DC, November 1977.

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APPENDIX A

MISCELLANEOUS DATA

Note: Previous editions of *Compilation of Air Pollutant Emission Factors* presented a table entitled Percentage Distribution by Size of Particles from Selected Sources without Control Equipment. Many of the data have become obsolete with the development of new information. As soon as the new information is sufficiently refined, a new table, complete with references, will be published for addition to this document.

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Table A-1. NATIONWIDE EMISSIONS FOR 1978[a]

Pollutant	Stationary combustion		Mobile combustion		Industrial processes		Solid Waste disposal		Miscellaneous[b]		Total	
	Mg/yr	ton/yr	Mg/yr	ton/yr	Mg/yr	ton/yr	Mg/yr	ton/yr	Mg/yr	ton/yr	Mg/yr	ton/yr
Particulates	3,800,000	4,200,000	1,300,000	1,400,000	6,200,000	6,800,000	500,000	600,000	700,000	800,000	12,500,000	13,800,000
Sulfur oxides	22,100,000	24,400,000	800,000	900,000	4,100,000	4,500,000	0	0	0	0	27,000,000	29,800,000
Nitrogen oxides	12,900,000	14,200,000	9,400,000	10,400,000	800,000	900,000	100,000	100,000	100,000	100,000	23,300,000	25,700,000
Hydrocarbons[c]	300,000	300,000	10,700,000	11,800,000	13,600,000	15,000,000	800,000	900,000	2,400,000	2,600,000	27,800,000	30,600,000
Carbon monoxide	1,200,000	1,300,000	85,500,000	94,200,000	7,600,000	8,400,000	2,700,000	3,000,000	5,100,000	5,600,000	102,100,000	112,500,000

[a] Based on National Air Pollutant Emission Estimates, 1970-1978 (EPA-450/4-80-002). Mg - megagrams (10^6 grams).

[b] Includes forest and agricultural burning, structural fires and nonindustrial organic solvent use.

[c] Expressed as nonreactive volatile organic compounds (VOC). Excluded are methane and other compounds defined as photochemically nonreactive in Recommended Policy on Control of Volatile Organic Compounds, 42 FR 35314, July 8, 1977.

Table A-5. GENERAL CONVERSION FACTORS

Type of substance	Conversion factors
Fuel	
Oil	1 bbl = 42 gal = 159 liters
Natural gas	1 therm = 100,000 Btu = 95 ft^3 1 therm = 25,000 kcal = 2.7 m^3
Agricultural products	
Corn	1 bu = 56 lb = 25.4 kg
Milo	1 bu = 56 lb = 25.4 kg
Oats	1 bu = 32 lb = 14.5 kg
Barley	1 bu = 48 lb = 21.8 kg
Wheat	1 bu = 60 lb = 27.2 kg
Cotton	1 bale = 500 lb = 226 kg
Mineral products	
Brick	1 brick = 6.5 lb = 2.95 kg
Cement	1 bbl = 375 lb = 170 kg
Cement	1 yd^3 = 2500 lb = 1130 kg
Concrete	1 yd^3 = 4000 lb = 1820 kg
Mobile sources	
Gasoline-powered motor vehicle	1.0 mi/gal = 0.426 km/liter
Diesel-powered motor vehicle	1.0 mi/gal = 0.426 km/liter
Steamship	1.0 gal/naut mi = 2.05 liters/km
Motorship	1.0 gal/naut mi = 2.05 liters/km
Other substances	
Paint	1 gal = 10 to 15 lb = 4.5 to 6.82 kg
Varnish	1 gal = 7 lb = 3.18 kg
Whiskey	1 bbl = 50 gal = 188 liters
Water	1 gal = 8.3 lb = 3.81 kg
Miscellaneous factors	1 lb = 7000 grains = 453.6 grams 1 ft^3 = 7.48 gal = 28.32 liters

REFERENCES FOR APPENDIX

1. Unpublished data file of nationwide emissions for 1970. Environmental Protection Agency, Office of Air Programs, Research Triangle Park, N.C.

2. Stairmand, C.J. The Design and Performance of Modern Gas Cleaning Equipment. J. Inst. Fuel. *29*:58-80. 1956.

3. Stairmand, C.J. Removal of Grit, Dust, and Fume from Exhaust Gases from Chemical Engineering Processes. London. Chem. Eng. p. 310-326, December 1965.

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ENGLISH TO METRIC FACTORS

To convert from	to	Multiply by
acre	metre^2 (m^2)	4.046 856 E+03
barrel (for petroleum, 42 gal)	metre^3 (m^3)	1.589 873 E-01
board foot	metre^3 (m^3)	2.359 737 E-03
British thermal unit (International Table)	joule (J)	1.055 056 E+03
British thermal unit (60°F)	joule (J)	1.054 68 E+03
bushel (U.S.)	metre^3 (m^3)	3.523 907 E-02
calorie (International Table)	joule (J)	4.186 800 E+00
calorie (20°C)	joule (J)	4.181 90 E+00
fluid ounce (U.S.)	metre^3 (m^3)	2.957 353 E-05
foot^3/second	metre^3/second (m^3/s)	2.831 685 E-02
foot^3	metre^3 (m^3)	2.831 685 E-02
foot^2	metre^2 (m^2)	9.290 304 E-02
foot/minute	metre/second (m/s)	5.080 000 E-03
foot/second	metre/second (m/s)	3.048 000 E-01
gallon (U.S. dry)	metre^3 (m^3)	4.404 884 E-03
gallon (U.S. liquid)	metre^3 (m^3)	3.785 412 E-03
gallon (U.S. liquid)/minute	metre^3/second (m^3/s)	6.309 020 E-05
grain	kilogram (kg)	6.479 891 E-05
horsepower (550 ft.lbf/s)	watt (W)	7.456 999 E+02
horsepower (boiler)	watt (W)	9.809 50 E+03
horsepower (electric)	watt (W)	7.460 000 E+02
horsepower (metric)	watt (W)	7.354 99 E+02
inch^2	metre^2(m^2)	6.451 600 E-04
inch^3	metre^3(m^3)	1.638 706 E-05
kilometre/hour	metre/second (m/s)	2.777 778 E-01
kilowatt-hour	joule (J)	3.600 000 E+06
knot	metre/second (m/s)	5.144 444 E-01
mile (U.S. statute)	metre (m)	1.609 344 E+03
mile^2 (U.S. statute)	metre^2 (m^2)	2.589 988 E+06
mile/hour (U.S. statute)	metre/second (m/s)	2.682 240 E+01
mile/hour (U.S. statute)	kilometre/hour	1.609 344 E+00
ounce-mass (avoirdupois)	kilogram (kg)	2.834 952 E-02
ounce-mass (troy or apothecary)	kilogram (kg)	3.110 348 E-02
quart (U.S. dry)	metre^3 (m^3)	1.101 221 E-03
quart (U.S. liquid)	metre^3 (m^3)	9.463 529 E-04
rod	metre (m)	5.029 200 E+00
section	metre^2 (m^2)	2.589 988 E+06
statute mile (U.S.)	metre (m)	1.609 344 E+03
ton (long)	kilogram (kg)	1.016 047 E+03
ton (metric)	kilogram (kg)	1.000 000 E+03
ton (short)	kilogram (kg)	9.071 847 E+02
township	metre^2 (m^2)	9.323 957 E+07
yard	metre (m)	9.144 000 E-01
yard^2	metre^2 (m^2)	8.361 274 E-01
yard^3	metre^3 (m^3)	7.645 549 E-01

CONVERSIONS

Temperature

Degrees Centigrade (Celsius) = 5/9 (°F - 32)
Degrees Farenheit = 9/5 (°C) + 32

Pressure

	PSI	Inches mercury	Bar	Atmosphere	Foot water
PSI	1.0	2.04	0.69	0.68	2.31
Inch mercury	0.491	1.0	0.0339	0.0334	1.13
Bar	14.5	29.51	1.0	0.986	33.41
Atmosphere	14.7	29.92	1.014	1.0	33.87
Foot water	0.434	0.884	0.030	0.0295	1.0

Length

	Milli-meter (mm)	Centi-meter (cm)	Meter (M)	Inch	Foot
Millimeter	1.00	0.01	0.001	0.0394	0.0033
Centimeter	10.0	1.00	0.01	0.3937	0.0328
Meter	1000.0	100.0	1.00	39.37	3.281
Inch	25.4	2.54	0.0254	1.00	0.083
Foot	304.8	30.48	0.3048	12.0	1.00

Area

	Sq. mm	Sq. cm	Sq. M	Sq. inch	Sq. foot
Sq. mm	1.0	0.1	1×10^{-6}	0.0016	1.1×10^{-5}
Sq. cm	100.0	1.0	1×10^{-4}	0.1550	0.0011
Sq. M	1×10^{6}	1×10^{4}	1.0	1550.0	10.764
Sq. inch	645.2	6.452	0.0006	1.0	0.0069
Sq. foot	92,903.0	929.03	0.0929	144.0	1.0

Volume

	Cu. Ft.	Quart	Gallon	Liter
Cu. Ft.	1.0	29.92	7.481	28.32
Quart	0.0334	1.0	0.250	0.946
Gallon	0.1337	4.0	1.0	3.784
Liter	0.0316	1.057	2.64	1.0

SOME USEFUL WEIGHTS AND MEASURES

grain	0.002	ounces	pound (troy)	12	ounces
gram	0.04	ounces	ton (short)	2000	pounds
ounce	28.35	grams	ton (long)	2240	pounds
kilogram	2.21	pounds	ton (metric)	2200	pounds
pound	0.45	kilograms	ton (shipping)	40	feet^3

centimeter	0.39	inches
inch	2.54	centimeters
foot	30.48	centimeters
meter	1.09	yards
yard	0.91	meters
mile	1.61	kilometers

centimeter^2	0.16	inches^2	centimeter^3	0.061	inches^3
inch^2	6.45	centimeters^2	inch^3	16.39	centimeters^3
foot^2	0.09	meters^2	foot^3	283.17	centimeters^3
meter^2	1.2	yards^2	foot^3	1728	inches^3
yard^2	0.84	meters^2	meter^3	1.31	yards^3
mile^2	2.59	kilometers^2	yard^3	0.77	meters^3

cord	128	feet^3	gallon (U.S.)	231	inches^3
cord	4	meters^3	barrel	31.5	gallons
peck	8	quarts	hogshead	2	barrels
bushel (dry)	4	pecks	township	36	miles^2
bushel	2150.4	inches^3	hectare	2.5	acres

MISCELLANEOUS DATA

One cubic foot of anthracite coal weighs about 53 pounds.

One cubic foot of bituminous coal weighs from 47 to 50 pounds.

One ton of coal is equivalent to two cords of wood for steam purposes.

A gallon of water (U.S. Standard) weighs 8.33 lbs. and contains 231 cubic inches.

There are 9 square feet of heating surface to each square foot of grate surface.

A cubic foot of water contains 7.5 gallons and 1728 cubic inches, and weighs 62.5 lbs.

Each nominal horsepower of a boiler requires 30 to 35 lbs. of water per hour.

A horsepower is equivalent to raising 33,000 pounds one foot per minute, or 550 pounds one foot per second.

To find the pressure in pounds per square inch of column of water, multiply the height of the column in feet by 0.434.

NATIONAL EMISSION DATA SYSTEM

SOURCE CLASSIFICATION CODES AND EMISSION FACTOR LISTING

SCC	PROCESS	POUNDS EMITTED PER UNIT PART	SO$_x$	NO$_x$	HC	CO	UNITS
MAJOR GROUP 72 - PERSONAL SERVICES							
Dry Cleaning - 7216							
4-01-001-03	Perchloroethylene	0.00	0.00	0.00	2000.	0.00	Tons solvent consumed
4-01-001-04	Stoddard	0.00	0.00	0.00	2000.	0.00	Tons solvent consumed
4-01-001-05	Trichlorotrifluoroethane (Freon)	0.00	0.00	0.00	2000.	0.00	Tons solvent consumed

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APPENDIX E

COMPILATION OF LEAD EMISSION FACTORS

INTRODUCTION

Lead was not involved as a specific pollutant in the earlier editions and supplements of AP-42. Since a National Ambient Air Quality Standard for lead has been issued, it has become necessary to determine emission factors for lead, and these are given in Table E-1. The AP-42 Section number given in this table for each process corresponds to the pertinant section in the body of the document.

Lead emission factors for combustion and evaporation from mobile sources require a totally different treatment, and they are not included in this Appendix.

Table E-1. UNCONTROLLED LEAD EMISSION FACTORS

AP-42 Section	Process	Emission factor[a,b] Metric	Emission factor[a,b] English	References
1.1	Bituminous coal combustion (all furnace types)	0.8 (L) kg/10^6 kg	1.6 (L) lb/10^3 ton	1,4-6
		(Average L = 8.3 ppm)		
1.2	Anthracite coal combustion (all furnace types)	0.8 (L) kg/10^6 kg	1.6 (L) lb/10^3 ton	1,4-6
		(Average L = 8.1 ppm)		
1.3	Residual fuel oil combustion (all boiler types)	0.5 (L) kg/$10^3 m^3$	4.2 (L) lb/10^6 gal	1,7
		(Average L = 1.0 ppm)		
1.3	Distillate fuel oil combustion (all boiler types)	0.5 (L) kg/$10^3 m^3$	4.2 (L) lb/10^6 gal	1,7
		(Average L = 0.1 ppm)		
1.7	Lignite combustion (all boiler types)	5-6 kg/10^6 kg	10-11 lb/10^3 tons	2
1.11	Waste oil combustion	9 (P) kg/m^3	75 (P) lb/10^3 gal	18,51,52
		(Average P - 1.0 percent)		
2.1	Refuse incineration (municipal incinerator)	0.2 kg/MT chgd	0.4 lb/ton chgd	1,3,9-11
2.5	Sewage sludge incineration (wet scrubber controlled)			
	Multiple hearth	.01-.02 kg/MT chgd	.02-.03 lb/ton chgd	3,12
	Fluidized bed	.0005-.002 kg/MT chgd	.001-.003 lb/ton	3,12

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Table E-1 (continued). UNCONTROLLED LEAD EMISSION FACTORS

AP-42 Section	Process	Emission factor[a,b]		References
		Metric	English	
5.22	Lead alkyl production			
	Electrolytic process	0.5 kg/MT prod	1.0 lb/ton prod	1,3,53
	Sodium-lead alloy process			
	Recovery furnace	28 kg/MT prod	55 lb/ton prod	1,53,54
	Process vents, TEL	2 kg/MT prod	4 lb/ton prod	1
	Process vents, TML	75 kg/MT prod	150 lb/ton prod	1
	Sludge pits	0.6 kg/MT prod	1.2 ton/ton prod	1
7.2	Metallurgical coke manufacturing	.00018 kg/MT coal chgd	.00035 lb/ton coal chgd	1,13,14
7.3	Primary copper smelting			
	Roasting	1.2 (P) kg/MT conc (Average P - 0.3 percent)	2.3 (P) lb/ton conc	1
	Smelting (reverberatory furnace)	0.8 kg/MT conc	1.7 lb/ton conc	1,15,17
	Converting	1.3 kg/MT conc	2.6 lb/ton conc	1,15,16,18
7.4	Ferroalloy production - electric arc furnace (open)			
	Ferrosilicon (50%); FeSi	0.15 kg/MT prod	0.29 lb/ton prod	20
	Silicon metal	0.0015 kg/MT prod	0.0031 lb/ton prod	1,19
	Silico-manganese	0.29 kg/MT prod	0.57 lb/ton prod	1,21
	Ferro-manganese (standard)	0.06 kg/MT prod	0.11 lb/ton prod	1,3
	Ferrochrome-silicon	0.04 kg/MT prod	0.08 lb/ton prod	20
	High carbon ferrochrome	0.17 kg/MT prod	0.34 lb/ton prod	20
7.4	Ferroalloy production - blast furnace	1.9 kg/MT prod	3.7 lb/ton prod	1,3
7.5	Iron and steel production			
	Sintering (windbox + vent discharges	0.0067 kg/MT sinter	0.013 lb/ton sinter	1,23,24
	Blast furnace for mixed charge)	0.062 kg/MT Fe	0.124 lb/ton Fe	1,23

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